THE USE OF COVER CROPS

FOR

NUTRIENT CONSERVATION

FINAL REPORT

ON

SWEEP-TED PROJECT

DSS No. XSE 89-0082-(302)

SER NO. 01686-9-0142/01-XSE

Prepared by

M.H. Miller
E.G. Beauchamp
T.J. Vyn
G.A. Stewart
J.D. Lauzon
R. Rudra

Centre for Soil and Water Conservation

University of Guelph

EXECUTIVE SUMMARY

Field experiments were conducted in 1990 and 1991 on a sandy loam soil at Ayr and a loam soil at Woodstock to evaluate the effectiveness of cover crops for nutrient conservation. Three cover crops, oilseed radish, annual ryegrass and red clover were established in 1990 in or following harvest of barley and winter wheat to which 1/2, 1 and 2x the recommended rates of N had been applied. Attempts to establish cover crops in corn were largely unsuccessful. Cover crops were sampled periodically to determine biomass production and N and P uptake. Soil and soil solution samples were taken periodically in the fall of 1990 and spring of 1991 and analyzed for NH_4^+ and NO_3 nitrogen. Corn was grown on all plots in 1991 without N addition to evaluate the release of N from the cover crops.

The potential for contribution of N and P to surface runoff by leaching from cover crops during the winter and spring was evaluated in laboratory leaching studies using a rainfall simulator.

Cover crop dry biomass at Ayr ranged from about 1000 kg ha^{-1} for ryegrass to over 4000 kg ha^{-1} for red clover. Differences were much less at Woodstock with cover crop biomass ranging from slightly below 2000 to slightly above 3000 kg ha^{-1}. Oilseed radish biomass following wheat at Ayr increased with increasing rate of N applied to the wheat but there were no other biomass responses to N rate on the main crop.

Red clover generally had the greatest biomass N content (kg ha^{-1}) while ryegrass had the least due primarily to the lower biomass production. Except for oilseed radish following wheat at Ayr, biomass N content was independent of N rate applied to the barley or wheat.

Oilseed radish had a considerably greater P concentration and biomass P

content (kg ha^{-1}) than either ryegrass or red clover.

Soil mineral N content (NH_4^+ and NO_3^-) in the upper 45 cm of soil was reduced by all cover crops compared to the check (no cover crop) in September. Mineral N contents decreased markedly at Woodstock by November even on the check plot. Mineral N contents of soil at Ayr did not change appreciably between the September and November samplings.

Concentrations of NO_3^--N in soil solution at the 75-cm depth were very low at Woodstock at all sampling times in the fall of 1990. This suggests that the decrease in soil mineral N content between September and November was most likely due to denitrification rather than leaching. At Ayr NO_3-N concentrations at 75-cm depth in September were below 10 mg L^{-1} under ryegrass and oilseed radish but were between 30 and 50 mg L^{-1} under red clover and the check. These latter values decreased to 2 mg L^{-1} by December indicating considerable leaching had occurred.

In April and May, NO_3-N contents of the soil profile were greater for oilseed radish than for other cover crops or the check, indicating that N was being released from this crop earlier than from ryegrass or red clover. In June, soil mineral N contents were much greater for red clover than other crops on the check. Mineral N contents on oilseed radish plots were only slightly greater than the check plot while those on ryegrass plots were lower than the check.

The mineral N contents in the soil were reflected in N contents of the 1991 corn crop in June and August which were greatest following red clover and least following ryegrass. Final grain yields reflected this greater N availability being greatest following red clover and least following ryegrass. These results indicate that N in oilseed radish is released earlier than desirable for use by the succeeding crop whereas ryegrass immobilizes N, with less being available than where no cover crop was grown. Release of N from red clover was closely related to the demands of the corn crop.

The laboratory rainfall simulation studies confirmed the ease of release of N from oilseed radish. A greater proportion (10-11%) of N in oilseed radish was removed during the leaching compared to 6-9% for ryegrass and 5-8% for red clover. In addition P concentrations in leachate from oilseed radish were much greater (10-14 mg L^{-1}) than for ryegrass (6-8 mg L^{-1}) or red clover (3-4 mg L^{-1}). Thus the potential for increased dissolved P in runoff from oilseed radish is much greater than for ryegrass or red clover.

The ideal cover crop, in terms of nutrient conservation, would be one which absorbs N rapidly in the fall, retains the N (and P) during winter and spring, then releases the N during the summer for use by the succeeding crop.

None of the three cover crops met all three of these criteria. Although oilseed radish absorbed N rapidly in the fall, it did not retain the N through the spring. In addition it increased the potential for dissolved P in spring runoff. Ryegrass appeared to absorb N and retain it through the winter and spring, but it did not release it rapidly enough for the succeeding crop. Red clover was very effective in retaining N through the winter and spring and in releasing it to the succeeding crop. There was, however, considerable leaching of NO_3-N from the red clover plot at Ayr.

All conclusions from this study must be interpreted with considerable caution because they are based on only a one-year study.

TABLE OF CONTENTS

EXECUTIVE SUMMARY i

LIST OF TABLES vii

LIST OF FIGURES viii

APPENDIX TABLES x

1.0 INTRODUCTION 1
  1.1 Objectives 5
  1.2 General approach 5

2.0 EXPERIMENTAL SITES, CULTURAL PRACTICES AND GRAIN YIELDS 7
  2.1 Experimental sites 7
  2.2 Cultural practices and yield of main crop 7
  2.3 Cultural practices for cover crops 7
  2.4 Cultural practices and yield of second year corn 11

3.0 COVER CROP EFFECTS ON SOIL N, N AND P UPTAKE AND N RELEASE 15
  3.1 Introduction 15
  3.2 Experimental procedures 15
    3.2.1 Cover crop sampling and analyses 15
    3.2.2 Soil sampling and analysis 16
    3.2.3 Soil solution sampling and analysis 16
  3.3 Results 16
    3.3.1 Cover Crop Biomass and N and P Contents 16
      3.3.1.1 Following barley at Ayr 16
      3.3.1.2 Following barley at Woodstock 17
      3.3.1.3 Following winter wheat at Ayr 23
      3.3.1.4 Following winter wheat at Woodstock 28
      3.3.1.5 Comparisons of cover crop responses following barley at the Ayr and Woodstock sites 28
    3.3.2 Mineral N contents of soil under cover crops following barley, winter wheat and corn 32
      3.3.2.1 Following barley 32
      3.3.2.2 Following winter wheat 35
      3.3.2.3 Following corn 38
    3.3.3 Nitrate and ammonium concentrations in soil solution below cover crops 38
      3.3.3.1 Ammonium concentrations 41
      3.3.3.2 Nitrate concentrations 41
    3.3.4 Response and N recovery by corn from previous cover crops 46
      3.3.4.1 From cover crops following Barley 46
      3.3.4.2 From cover crops following winter wheat . . . 51
      3.3.4.3 From cover crops following corn 51
      3.3.4.4 Summary of cover crop N benefits 51

4.0 LEACHING OF NITROGEN AND PHOSPHORUS FROM COVER CROPS 61

4.1 Introduction 61
4.2 Experimental procedures 63
4.3 Results 65
    4.3.1. Temporal pattern of leaching 65
    4.3.2. Influence of cover crop and leaching conditions on mean concentrations of nutrients in leachate 68
        4.3.2.1 Ammonium-N 68
        4.3.2.2. Nitrate-N 72
        4.3.2.3 Phosphorus 74

    4.3.3 Influence of cover crop and leaching conditions on amount of nutrient leached per unit mass of cover crop 77
    4.3.4 Proportion of nutrient in biomass removed by leaching 81
    4.3.5 Organic nitrogen, phosphorus and carbon in leachate . 83
4.4 Discussion and conclusions 83

5.0 SUMMARY AND CONCLUSIONS 85

6.0 REFERENCES 87

APPENDIX TABLES 89

LIST OF TABLES

Table 2.1. Management practices and grain yields for main crops at Ayr. 8

Table 2.2. Management practices and grain yields for main crops at Woodstock. 9

Table 2.3. Management practices for establishing various cover crops with the associated main crops at both Ayr and Woodstock locations. 10

Table 2.4. The effect of previous main crops, cover crops and nitrogen rates on the following grain corn yields at Woodstock in 1991. 12

Table 2.5. The effect of previous main crops, cover crops and nitrogen rates on the following grain corn yields at Ayr in 1991. . . 13

Table 3.1: Concentrations of NH_4^+-N in the soil solution (75cm) with cover crop treatments at different dates following barley at the Ayr site (1990) 42

Table 3.2: Concentration of NH_4^+-N in the soil solution (75 cm) with cover crop treatments at different dates following winterwheat at the Ayr site (1990) 42

Table 3.3: Concentration of NH_4^+-N in the soil solution (75 cm) with cover crop treatments at different dates following barley at the Woodstock site (1990-91) 43

Table 3.4: Concentration of NH_4^+-N in the soil solution (75 cm) with cover crop treatments at different dates following winterwheat at the Woodstock site (1990-91) 43

Table 3.5: Concentration of NH_4^+-N in the soil solution (75 cm) with cover crop treatments following corn at the Ayr site (1990) . 43

Table 3.6: Concentration of NH_4^+-N in the soil solution (75 cm) with cover crop treatments at different dates following corn at the Woodstock site (1990-91) 44

Table 3.7: Concentration of NO_3^--N in the soil solution (75 cm) with cover crop treatments at different dates following barley at the Ayr site (1990) 44

Table 3.8: Concentration of NO_3^--N in the soil solution (75 cm) with cover crop treatments at different dates following winterwheat at the Ayr site (1990) 44

Table 3.9: Concentration of NO_3^--N in the soil solution (75 cm) with cover crop treatments at different dates following barley at the Woodstock site (1990-91) 45

Table 3.10: Concentration of $NO_3^{\$}$-N in the soil solution (75 cm) with cover crop treatments at different dates following winterwheat at the Woodstock site (1990-91) 45

Table 3.11: Concentration of $NO_3^{\$}$-N in the soil solution (75 cm) with cover crop treatments following corn at the Ayr site (1990) 45

Table 3.12: Concentration of $NO_3^{\$}$-N in the soil solution (75 cm) with cover crop treatments at different dates following corn at the Woodstock site (1990-91) 46

Table 4.1. Comparisons of main effects of leaching variables on mean concentration of NH_4-N in leachate. 69

Table 4.2: Comparisons of main effects of leaching variables on mean concentration of $N0_3$-N in leachate. 72

Table 4.3: Comparisons of main effects of leaching variables on mean concentration of P in leachate. 77

Table 4.4: Amount of NH_4-N leached per unit of biomass. 78

Table 4.5: Amount of $N0_3$-N leached per unit of biomass. 79

Table 4.6: Amount of P leached per unit of biomass. 79

Table 4.7: Proportion of N in cover crop biomass removed by leaching. . 82

Table 4.8: Proportion of P in cover crop biomass removed by leaching. . 82

LIST OF FIGURES

Fig. 3.1 Dry biomass yields of cover crops following barley at three N levels at the Ayr site. 18

Fig. 3.2 Biomass N content of three cover crops following barley at three N levels at the Ayr site. 19

Fig. 3.3 Biomass P content of three cover crops following barley at three N levels at the Ayr site. 20

Fig. 3.4 Dry biomass yields of cover crops following barley at three N levels at the Woodstock site. 21

Fig. 3.5 Biomass N content of three cover crops following barley at three N levels at the Woodstock site. 22

Fig. 3.6 Biomass P content of three cover crops following barley at three N levels at the Woodstock site. 24

Fig. 3.7 Dry biomass yields of three cover crops following winter wheat at three N levels at the Ayr site. 25

Fig. 3.8 Biomass N content of three cover crops following winter wheat a three N levels at the Ayr site. 26

Fig. 3.9 Biomass P content of three cover crops following winter wheat at three N levels at the Ayr site. 27

Fig. 3.10 Dry biomass yields of three cover crops following winter wheat at three N levels at the Woodstock site 29

Fig. 3.11 Biomass N content of three cover crops following winter wheat at three N levels at the Woodstock site 30

Fig. 3.12 Biomass P content of three cover crops following winter wheat at three N levels at the Woodstock site 31

Fig. 3.13 Ammonium, nitrate and mineral N contents to the 45 cm depth with cover crops at samplings in the fall (1990) and spring (1991) following barley at the Ayr site 33

Fig. 3.14 Ammonium, nitrate and mineral N contents to the 45 cm depth with cover crops at samplings in the fall (1990) and spring (1991) following barley at the Woodstock site 34

Fig. 3.15 Ammonium, nitrate and mineral N contents to the 45 cm depth with cover crops at samplings in the fall (1990) following winter wheat at the Ayr site 36

Fig. 3.16 Ammonium, nitrate and mineral N contents to the 45 cm depth with cover crops at samplings in the fall (1990) and spring (1991) following winter wheat at the Woodstock site 37

Fig. 3.17 Ammonium, nitrate and mineral N contents to the 45 cm depth with cover crops at samplings in the fall (1990) and spring (1991) following corn at the Ayr site. 39

Fig. 3.18 Ammonium, nitrate and mineral N contents to the 45 cm depth with cover crops at samplings in the fall (1990) and spring (1991) following corn at the Woodstock site. 40

Fig. 3.19 Dry biomass yield of corn in June and August following different cover crops following barley at the Ayr site. . . . 47

Fig. 3.20 Corn biomass N content in June and August following different cover crops following barley at the Ayr site. . . . 48

Fig. 3.21 Dry biomass yield of corn in June and August following different cover crops following barley at the Woodstock site. 49

Fig. 3.22 Corn biomass N content in June and August following different cover crops and barley at the Woodstock site. . . . 50

Fig. 3.23 Dry biomass yield of corn in June and August following different cover crops following winter wheat at the Woodstock site. 52

Fig. 3.24 Corn biomass N content in June and August following different cover crops following winter wheat at the Woodstock site. 53

Fig. 3.25 Dry biomass yield of corn in June and July following different cover crops, following corn at the Ayr site. . . . 54

Fig. 3.26 Corn biomass N content in June and July following different cover crops following corn at the Ayr site. 55

Fig. 3.27 Dry biomass yield of corn in June and August following cover crops following corn at the Woodstock site. 56

Fig. 3.28 Corn biomass N content in June and August following cover crops following corn at the Woodstock site. 57

Fig. 3.29 Change in biomass N content of corn following different cover crops relative to the no cover crop treatment in June and August with different N levels (Average of both cereal crops at both sites). 58

Fig. 3.30 Change in dry biomass of corn following different cover crops relative to the no cover crop treatment in June and August with different N levels at both sites (Average of both cereal crops at both sites) 59

Fig. 4.1 Temporal pattern of nutrient concentration in leachates during first leaching 66

Fig. 4.2 Temporal pattern of nutrient concentration in leachates during second leaching 67

Fig. 4.3 NH_4-N concentration in leachate from ryegrass-high N treatment as influenced by loading rate and intensity during the first and second leaching 70

Fig. 4.4 NH_4-N concentration in leachate from red clover-high N treatment as influenced by freeze/dry treatment during first and second leaching 71

Fig. 4.5 NO_3-N concentration in leachate from ryegrass-low N treatment as influenced by intensity and freeze/dry treatment during first and second leaching 73

Fig. 4.6 NO_3-N concentration in leachate from red clover-low N treatment as influenced by loading rate and freeze/dry treatment during first and second leaching 75

Fig. 4.7 P concentration in leachate from oilseed radish-high N treatment as influenced by freeze/dry treatment at first and second leaching 76

Fig. 4.8 Amount of P leached from oilseed radish-low N treatment as influenced by leaching intensity during first and second leaching 80

APPENDIX TABLES

Appendix A - Cover Crop Biomass at Each of Three Harvests

- Table A1 - Cover Crop Biomass - Ayr
- Table A2 - Cover Crop Biomass - Woodstock

Appendix B - N and P Concentrations in Cover Crop Biomass at Each of Three Harvests

- Table B1 - Harvest 1, Nitrogen and Phosphorus Concentration in Cover Crop Biomass
- Table B2 - Harvest 2, Nitrogen and Phosphorus Concentration in Cover Crop Biomass
- Table B3 - Harvest 3, Nitrogen and Phosphorus Concentration in Cover Crop Biomass

Appendix C - NH_4-N and NO_3-N Concentrations in Soils at Different Dates for Each Cover Crop/N Rate and Soil Depth

- Table C1 - Ayr Barley
- Table C2 - Ayr Corn
- Table C3 - Ayr Wheat
- Table C4 - Woodstock Barley
- Table C5 - Woodstock Corn
- Table C6 - Woodstock Wheat

Appendix D - Biomass and N Concentration of Second Year Corn at Two Dates for Each Cover Crop/N Combination

- Table D1 - Ayr Barley
- Table D2 - Ayr Corn
- Table D3 - Woodstock Barley
- Table D4 - Woodstock Corn
- Table D5 - Woodstock Wheat

Appendix E - Volume of Leachate and Concentration of Ammonium (NH_4-N), Nitrate (NO_3-N) and Phosphorus for Each Sampling Interval During the Leaching Period

- Table E1 - Ryegrass, Low N - Volume (mL)
- Table E2 - Ryegrass, Low N - NH_4-N (mg L^{-1})
- Table E3 - Ryegrass, Low N - NO_3-N (mg L^{-1})
- Table E4 - Ryegrass, Low N - P (mg L^{-1})
- Table E5 - Ryegrass, High N - Volume (ml)
- Table E6 - Ryegrass, High N - NH_4-N (mg L^{-1})
- Table E7 - Ryegrass, High N - NO_3-N (mg L^{-1})
- Table E8 - Ryegrass, High N - P (mg L^{-1})
- Table E9 - Oilseed Radish, Low N - Volume (ml)
- Table E10 - Oilseed Radish, Low N - NH_4-N (mg L^{-1})
- Table E11 - Oilseed Radish, Low N - NO_3-N (mg L^{-1})

Table E12 - Oilseed Radish, Low N - P (mg L^{-1})
Table E13 - Oilseed Radish, High N - Volume (ml)
Table E14 - Oilseed Radish, High N - NH_4-N (mg L^{-1})
Table E15 - Oilseed Radish, High N - NO_3-N (mg L^{-1})
Table E16 - Oilseed Radish, High N - P (mg L^{-1})
Table E17 - Red Clover, Low N - Volume (mL)
Table E18 - Red Clover, Low N - NH_4-N (mg L^{-1})
Table E19 - Red Clover, Low N - NO_3-N (mg L^{-1})

Table E20 - Red Clover, Low N - P (mg L^{-1})
Table E21 - Red Clover, High N - Volume (mL)
Table E22 - Red Clover, High N - NH_4-N (mg L^{-1})
Table E23 - Red Clover, Hign N - NO_3-N (mg L^{-1})
Table E24 - Red Clover, High N - P (mg L^{-1})

Appendix F - Weighted Mean Concentration of NH_4-N, NO_3-N, and P in Leachates From Cover Crops and Statistical Significance of Effects

Table F1 - Weighted mean concentration of NH_4-N
Table F2 - Statistical significance of Weighted Mean Concentration of NH_4-N
Table F3 - Weighted mean concentration of NO_3-N
Table F4 - Statistical significance of Weighted Mean Concentration of NO_3-N
Table F5 - Weighted mean concentration of P
Table F6 - Statistical significance of Weighted Mean Concentration of P

Appendix G - Amount of Nutrient Leached Per Unit Weight of Cover Crop (MG KG^{-1}) and Statistical Significance of Effects

Table G1 - Amount of NH_4-N leached per unit weight of cover crop
Table G2 - Statistical significance of effects - NH_4-N
Table G3 - Amount of NO_3-N leached per unit weight of cover crop
Table G4 - Statistical significance of effects - NO_3-N
Table G5 - Amount of P leached per unit weight of cover crop
Table G6 - Statistical significance of effects - P

Appendix H - Proportion of N and P Removed From Cover Crop Biomass by Leaching

Table H1 - Proportion of N content of biomass removed by leaching
Table H2 - Proportion of P content of biomass removed by leaching

1.0 INTRODUCTION

A sustainable crop production system must maintain or enhance the quality of soil and water resources and, at the same time, provide a satisfactory return to the producer for labour and investment. A major concern in Ontario is the deterioration of soil and water quality associated with crop production.

Intensive crop production has several deleterious effects on soil and water quality. The intensive cultivation associated with the conventional production practices (moldboard plowing and secondary cultivation) exposes the soil to the forces of wind and water erosion, particularly during the winter and spring months, and also reduces the organic matter in the soil. The reduction in organic matter increases the erodability of the soil and also increases the susceptibility of the soil to compaction. The intensive use of pesticides and fertilizer, particularly nitrogen, increases the potential for contamination of surface and groundwater supplies. Excess concentration of nitrate-nitrogen (NO_3-N) in drinking water can cause blue baby syndrome (methemoglobinemia) in infants and is also a health hazard for ruminant animals. A number of states in the U.S.A. have recently imposed restrictions on fertilizer use because of excessive NO_3-N concentrations in groundwater in areas of intensive crop production. Restrictions have also been placed on residential developments dependent on groundwater because of excessive NO_3-N levels. Instances of NO_3-N concentrations in excess of the established safe level (10 mg NO_3-N per litre) have been observed in Ontario in association with intensive crop production.

The main period of potential leaching in Ontario is in the fall after the crop has been harvested and in the late winter and spring before the succeeding crop is transpiring a significant amount of water. At these times the evaporation is considerably less than precipitation. Any NO_3-N present in the soil at these times is subject to leaching. The presence of a growing crop during the fall would reduce the NO_3-N content of the soil and hence the potential for leaching.

There have been several studies in Ontario in recent years on the establishment of cover crops, on their role in soil structural stability and on their contribution of nitrogen to the succeeding crop. Studies with red clover at the Elora Research Station (Sheard, 1988) indicate the improvement in aggregation created by one season's growth of red clover underseeded in barley is somewhat less than that created if the red clover is maintained for an additional year as a forage. The nitrogen credit from the red clover after one growing season underseeded in barley will range from 45 kg N/ha for a grain corn crop. Through the use of red clover and alfalfa labelled in situ with ^{15}nitrogen it has been demonstrated (Alder, 1988) that the availability of nitrogen from the residues to the succeeding corn or barley crop is largely independent of whether or not the residues are incorporated.

The successful establishment of red clover under silage corn has been demonstrated on experimental plots located on a medium textured soil in the 2600 corn heat unit zone (Sheard, 1988). Establishment is dependent on two management techniques: the use of a herbicide which is compatible with both corn and red clover and the stage of development of the corn relative to the date of planting the red clover.

Several additional studies have been or are currently being conducted to determine the most appropriate management systems for establishing cover crops and to determine the influence of the cover crops on soil properties and erosion.

During the period from 1982 to 1985, Agriculture Canada funded rye cover crop research at Elora and Woodstock. Although the primary emphasis of this project was on biomass production with the combination of rye silage and fodder corn, much research was also devoted to the management aspects of rye planting systems and rye harvest (or chemical control) systems before planting corn. One conclusion from this research was that rye should be killed approximately two weeks before planting corn in order to avoid the prospect of slower corn growth rates and 20 or 30% corn yield reductions (Daynard et al. 1985).

None of the above studies addressed the role of the cover crop as a sink for nitrate nitrogen remaining in the soil following harvest of the main crop. Studies elsewhere have shown that nonleguminous cover crops can absorb as much as 90 kg N ha^{-1}, although in most cases the range was 25 to 45 kg N ha^{-1} (Wagger and Mengel, 1988). The amount of N in the cover crop was related to residual N in the soil which in turn was related to the N application to the main crop relative to the N absorbed by that crop. The N content of a rye cover crop increased from 26 to 66 kg N ha^{-1} as the N application to the previous corn crop increased from 0 to 170 kg N ha^{-1} (Wagger and Mengel, 1988). None of these studies, however, appears to have measured the residual NO_3-N in the soil. Hence the degree to which leaching of NO_3-N to the ground water was reduced is not clear.

The effect of a cover crop on the amount of nitrogen leached is complex. Plant uptake will reduce the quantity of NO_3-N in the soil and the plants will increase evapotranspiration decreasing the quantity of water in the soil to transport the NO_3-N. But, the rate of rainfall infiltration may be increased by cover crop use due to a decrease in surface run off. The decreased potential of leaching due to evapotranspiration, and the increased potential for leaching due to increased infiltration are controlled by many climatic and crop factors so is very difficult to predict. A deep and densely rooted cover crop will be more capable of intercepting NO_3-N in the soil. A quickly growing cover crop will be more capable of removing excess NO_3 from the soil before it has time to be leached.

Meisinger et al (1991) have reviewed the literature dealing with the quantity of nitrogen leached under a variety of cover crops. The first group of studies used grass cover crops (mainly rye). The studies all showed similar results. The use of a grass cover crop reduced the mass of nitrogen leached by 60 percent and the concentration of NO_3-N in leachate of 50 percent on average. A second group of studies considered the Brassica genus including the species radish, rape seed, turnip, and mustard. These cover crops were found to reduce N transported through leaching by 60 to 70 percent. A third group of studies compared legume to nonlegume cover crops. The nonlegumes were consistently superior at reducing N leaching. Leaching with nonlegumes was reduced by 70 percent and that with the legumes only 23 percent. Thus although legume crops have the advantage of providing additional N to the succeeding crop, they are unlikely to be as effective as a sink for residual soil NO_3-N.

The role of a legume crop in supplying nitrogen to the succeeding crop has been investigated extensively, but the role of nonleguminous crops has received little attention. Wagger and Mengel (1988) stated that "a nonleguminous cover crop could either increase the N availability to a subsequent crop by the trapping or capture of residual soil N, or could reduce N availability through competition or immobilization". They also state that "while our intuitive understanding of these potential effects is generally agreed upon by scientists, good examples from published data are somewhat scarce".

Doran and Smith (1991) have reviewed the literature on cover crop fertilizer N equivalency. Based on several U.S. locations the N fertilizer equivalency of nonlegume cover crops was found to be low or negligible (perhaps negative). This is likely due to lower N content and higher C/N ratios which result in immobilization of N during the growing season. McCracken et al (1989) found that a rye cover crop had little to no effect on corn N uptake and grain yield over fallow plots. The same experiment observed that Hairy vetch increased corn grain yield by 20 bu ac^{-1} and increased N uptake by 30 kg ha^{-1} (@ 8 weeks after planting). Legumes were superior to nonlegumes in all cases in supplying subsequent crops with nitrogen. Sampson et al (1991) reported on Ontario studies comparing the nitrogen contribution to a succeeding corn crop from red clover, crimson clover, hairy vetch and oilseed radish. Corn yields following hairy vetch were equivalent to those of corn receiving about 100 kg N ha^{-1}. Other cover crops produced corn yields equivalent to those with about 70 kg N ha^{-1}. Oilseed radish was less effective than legumes in providing N to corn, particularly during early growth. The authors attributed this to the immobilization of nitrogen during decomposition of the oilseed radish residues.

In spite of the benefits from cover crops, a potential detrimental effect on water quality does exist. It has been established that nutrients can be leached from the dead foliage and increase the concentration in runoff. This is of particular concern for phosphorus but also, to a lesser extent, for nitrogen. Any evaluation of the effectiveness of cover crops in reducing the impact of a cropping system on water quality must also consider this potential detrimental effect.

1.1 Objectives

The objectives of this project were:

1. To determine the ability of legume and nonlegume cover crops to reduce the residual NO_3-N in the soil following harvesting of the principal crop.
2. To determine the effect of legume and nonlegume cover crops on the N supply to the succeeding crop.
3. To determine the effect of the cover crop on N and P concentrations in runoff.

1.2 General approach

Experiments were established at two locations. One main crop, winter wheat, was established in the fall of 1989. Two additional main crops, corn and barley, were established in the spring of 1990. Three rates of N fertilizer (1/2, 1 and 2 times recommended) were applied to establish variable residual N levels. Three cover crops plus a control (no cover crop) were established in the plots during the spring and summer of 1990. A corn crop without N addition was grown on all plots in 1991 to evaluate the influence of the cover crop on the nitrogen supply to the succeeding crop. The NO_3-N content of the soil and soil solution, the biomass and N content of the cover crops and the second-year corn crop were monitored periodically.

Samples of biomass from selected treatments of each cover crop were collected prior to cessation of growth in the fall of 1990. These samples were frozen and later subjected to leaching using a laboratory rainfall simulation system to determine the extent of leaching of nitrogen and phosphorus.

Detailed procedures, results and discussion on the three components of the study are reported in succeeding sections. Section 2 includes the cultural practices used to establish the three main crops and the cover crops. Also presented in Section 2 are grain yields for the three main crops in 1990 and for the corn crop in 1991. Section 3 includes the cover crop biomass and N contents as well as the nitrate-nitrogen content of the soil and soil solution. Section 4 includes the results of the studies on nutrient leaching from the cover crops. In Section 5 the information from the three preceding sections is integrated and over-all conclusions are presented.

2.0 EXPERIMENTAL SITES, CULTURAL PRACTICES AND GRAIN YIELDS

2.1 Experimental sites

Experimental sites selected for this study were a farm site at Ayr (sandy loam) and the Woodstock Research Station (loam). At each site, separate sets of plots were established for each main crop, barley, wheat and corn. For each main crop, three replicates of a split plot design were established with N rate as the main plot and cover crop as the sub-plot.

2.2 Cultural practices and yield of main crop

Details of the main crop management practices are outlined for the Ayr and Woodstock sites in Tables 1 and 2 respectively. All main crops grew very well throughout the 1990 season except for some early drought stress on the winter wheat and barley at Ayr. There were no significant grain yield responses to the three nitrogen rates (0.5, 1.0 and 2.0 times recommended rates) for any of the main crops at either Ayr or Woodstock. These yield results indicated that sufficient N was available in the soil, even at the low nitrogen rate, for main crop growth. Furthermore, the early cover crop growth was not likely to have been limited by soil nitrogen levels.

2.3 Cultural practices for cover crops

Cover crops were established at Ayr and Woodstock as outlined in Table 3. Cover crops of oilseed radish, annual ryegrass and red clover were established successfully in both barley and wheat at both locations. However, attempts to grow red clover, winter rye and annual ryegrass within the corn crop were generally unsuccessful. Most of the cover crops seemed to emerge satisfactorily under the corn but growth was very poor. It is suggested that light competition from the corn crop, which produced over 7 tonnes ha^{-1} of dry grain (150 bu ac^{-1} @ 15.5% moisture) was responsible for the poor cover crop growth. It was decided that harvesting of red clover and ryegrass cover crops would not be attempted. Five out of 9 plots with winter rye underseeded in corn were harvested but rye biomass was low (ranging from 0.2 to 1.5 t/ha in mid October).

Table 2.1. Management practices and grain yields for main crops at Ayr.

Management Practice	Previous Main Crop		
	Barley	Wheat	Corn
Seeding date	April 23, 1990	Oct. 2, 1989	May 4, 1990
Seeding rate	100 kg ha^{-1}	100 kg ha^{-1}	73,800 plants ha^{-1}
Cultivar	Leger	Harus	P3790
Fertilizer at Planting			
P (kg P_2O_5 ha^{-1})	38	38	38
K (kg K_2O ha^{-1})	38	38	38
Nitrogen rates (as 33-0-0 broadcast)	25,50,100 kg N ha^{-1}	45,90,180 kg ha^{-1}	75,150,300 kg ha^{-1}
Date of N application	April 23, 1990	April 18, 1990	May 4, 1990
Herbicides	Tropotox (3.5 L ha^{-1})	Tropotox (4 L ha^{-1})	Eradicane (6 L ha^{-1})
Harvest date	August 1, 1990	July 25, 1990	Oct. 16, 1990
Grain yields (0% moisture)			
0.5 N	2.29 Mg ha^{-1}	3.00 Mg ha^{-1}	7.48 Mg ha^{-1}
1.0 N	2.23 Mg ha^{-1}	3.00 Mg ha^{-1}	8.18 Mg ha^{-1}
2.0 N	1.90 Mg ha^{-1}	2.95 Mg ha^{-1}	7.76 Mg ha^{-1}

Table 2.2. Management practices and grain yields for main crops at Woodstock.

Management Practice	Previous Main Crop		
	Barley	Wheat	Corn
Seeding date	April 26, 1990	Oct. 5, 1991	May 3, 1990
Seeding rate	84 kg ha^{-1}	100 kg ha^{-1}	73,800 plants ha^{-1}
Cultivar	Leger	Harus	P3790
Fertilizer at Planting			
P (kg P_2O_5 ha^{-1})	38	38	38
K (kg K_2O ha^{-1})	38	38	38
Nitrogen rates (as 33-0-0 broadcast)	25,50,100 kg N ha^{-1}	45,90,180 kg N ha^{-1}	75,150,300 kg N ha^{-1}
Date of N application	April 26, 1990	April 18, 1990	May 3, 1990
Herbicides	MCPA (1.5 L ha^{-1})	Tropotox (4 L ha^{-1})	Bladex (2.5 L ha^{-1}) Eradicane (6 L ha^{-1})
Harvest date	August 2, 1990	July 26, 1990	Oct. 22, 1990
Grain yields (0% moisture)			
0.5 N	3.92 Mg ha^{-1}	4.81 Mg ha^{-1}	9.00 Mg ha^{-1}
1.0 N	4.07 Mg ha^{-1}	5.01 Mg ha^{-1}	9.24 Mg ha^{-1}
2.0 N	4.06 Mg ha^{-1}	4.63 Mg ha^{-1}	9.15 Mg ha^{-1}

Table 2.3. Management practices for establishing various cover crops with the associated main crops at both Ayr and Woodstock locations.

Cover crop and Management Practices	Main Crop		
	Barley	Wheat	Corn
Oilseed Radish			
Seeding time	Early August (post-harvest)	Early August (post-harvest)	Not applicable
Seeding rate	20 kg ha^{-1}	20 kg ha^{-1}	
Seeding method	Disced and drilled	Disced and drilled	
Herbicides or other practices	Fusilade (0.8 L ha^{-1}) to control volunteer barley	Fusilade (0.8 L ha^{-1}) to control volunteer wheat	
Annual Ryegrass			
Seeding time	Same as barley	Early July	Early July
Seeding rate	15 kg ha^{-1}	15 kg ha^{-1}	15 kg ha^{-1}
Seeding method	Broadcast + Pack	Broadcast	Broadcast + rake
Red Clover			
Seeding time	Same as barley	Early June	Early June
Seeding rate	15 kg ha^{-1}	15 kg ha^{-1}	15 kg ha^{-1}
Seeding method	Broadcast + Pack	Broadcast	Drilled
Winter Rye			
Seeding time	Not applicable	Not applicable	Mid September
Seeding rate			175 kg ha^{-1}
Seeding method			Broadcast

2.4 Cultural practices and yield of second year corn.

On May 3, 1991 all experimental sites were sprayed with Roundup (2.5 L ha^{-1}). The Ayr sites were then chisel plowed (sweep teeth) and field cultivated on May 9 and planted to corn on May 10. At Woodstock, chisel plowing and field cultivation occurred on May 14 and 15 and corn was planted on May 16, 1991. Pioneer 3790 was the corn hybrid seeded at all sites. No nitrogen fertilizer was applied to the corn except a small amount in the starter fertilizer (14 kg N ha^{-1}).

At both Ayr and Woodstock, seedbeds were considerably rougher where ryegrass had been grown compared to the other cover crops. This was caused by rather large masses of ryegrass sod which proved to be very tough to break down with the tillage practices employed. The use of planter mounted coulters and disc-furrowers ameliorated planting conditions. However, some concern was expressed over poor seed/soil contact whenever corn followed the ryegrass sub-treatment. Probably, as a result of this condition, final corn plant populations were significantly lower following the ryegrass cover crop at Woodstock where the main crop was winter wheat. At this site corn plant populations were approximately 13% lower following ryegrass than following any of the other cover crops when averaged across all previous main crops. Plant populations at the other sites were not significantly different.

The poor growth of cover crops within the corn main crop precluded further data collection on these sites at both Ayr and Woodstock. The following corn crop was harvested, however, on selected treatments at these sites that had achieved at least some cover crop growth by the fall of 1990. The farm co-operator at Ayr accidentally spread manure and disced the wheat main crop site thus eliminating it from further study.

Table 2.4. The effect of previous main crops, cover crops and nitrogen rates on the following grain corn yields at Woodstock in 1991.

N	Cover	Previous Main Crop		
Rate	Crop	Barley	Wheat	Corn
		-------- Mg ha^{-1} (15.5% moisture)		-------
1/2X	None	9.33 b*	8.62 b	6.78 a
	Oilseed radish	9.18 b	9.25 b	-
	Ryegrass	7.36 c	5.80 c	-
	Red clover	10.37 a	10.43 a	-
	Winter rye	-	-	7.07 a
	mean	9.05 j#	8.52 j	6.92 j
1X	None	8.33 c	9.70 b	7.37 a
	Oilseed radish	9.18 bc	9.48 b	-
	Ryegrass	9.34 b	7.09 c	-
	Red clover	10.51 a	10.64 a	-
	Winter rye	-	-	6.96 a
	mean	8.70 j	9.23 j	7.17 j
2X	None	9.30 b	9.07 b	8.28 a
	Oilseed radish	9.18 b	9.83 b	-
	Ryegrass	7.34 c	7.42 c	-
	Red clover	11.12 a	10.65 a	-
	Winter rye	-	-	7.70 a
	mean	9.55 j	9.24 j	8.0 j

* Within a main treatment (nitrogen rate), sub-treatment (cover crop) yields followed by the same letter are not significantly different (P=0.05).

# Main treatment means followed by the same letter are not significantly different (P=0.05).

Table 2.5. The effect of previous main crops, cover crops and nitrogen rates on the following grain corn yields at Ayr in 1991.

N Rate	Cover Crop	Previous Main Crop	
		Barley	Corn
		-(Mg ha^{-1} (15.5% moisture)-	
1/2X	None	7.79 b*	6.18 a
	Oilseed radish	9.50 a	-
	Ryegrass	6.96 b	6.15 a
	Red clover	10.51 a	-
	Winter Rye	-	5.61 a
	mean	8.69 j#	5.98 j
1X	None	6.95 b	5.79 a
	Oilseed radish	8.17 ab	-
	Ryegrass	7.74 b	5.64 a
	Red clover	9.59 a	-
	Winter Rye	-	5.83 a
	mean	8.10 k	5.76 j
2X	None	7.02 b	6.13 a
	Oilseed radish	8.19 b	-
	Ryegrass	7.02 b	6.02 a
	Red clover	10.04 a	-
	Winter Rye	-	6.46 a
	mean	7.93 k	6.20 j

* Within a main treatment (nitrogen rate), sub-treatment yields (cover crop) followed by the same letter are not significantly different (P=0.05).

# Main treatment means followed by the same letter are not significantly different (P=0.05).

Grain yields of the following corn crop are presented in Tables 4 and 5 for Woodstock and Ayr respectively. The most significant trend across all sites was for corn following red clover to yield significantly more than corn following all other previous cover crops. This occurred regardless of the previous main crop or the nitrogen rate applied to that main crop in the previous year. At Woodstock corn yields following the ryegrass cover crop were consistently lower than when corn followed any of the other previous crops. Some part of this yield response may have been due to the coarser seedbed conditions which followed this cover crop.

3.0 COVER CROP EFFECTS ON SOIL N, N AND P UPTAKE AND N RELEASE

3.1 Introduction

The production of biomass and uptake of N and P by different cover crops are presented and discussed in this chapter. In addition, ammonium and nitrate concentrations and contents in the soil with different cover crop treatments following each of the three main crops at the Ayr and Woodstock sites will be discussed. Finally, the release of N from the cover crop biomass to a succeeding corn crop will be evaluated.

3.2 Experimental procedures

3.2.1 Cover crop sampling and analyses

The biomass yields of the cover crop was determined three times in the fall of 1990 for the wheat and barley plots and once for the corn plots. Only the annual rye grass in the wheat and barley plots was sampled in the spring of 1991 (red clover and oilseed radish crops were too matted down to obtain representative biomass samples). The N and P concentrations of the cover crops were determined and along with biomass yields were used to calculate N and P contents. The corn crop biomass and biomass N concentration was determined in mid June and early August in 1991.

Biomass samples were taken from 2.25 m^2 areas from the cover crop plots and the corn crop in 1991. Cover crop samples were obtained by cutting the stems of the plants just above the soil surface from a 1 m x 2.25 m area. Subsamples were taken to the laboratory for determination of biomass yield, and N and P contents. The crop samples obtained in 1991 were cut just above the soil surface from a 1.5 m wide (two corn rows) x 1.5 m area. The entire harvested sample at the first sampling date was taken to the lab for analysis but at the second sampling date four plants were subsampled for N determinations. The nitrogen benefit/deficit in the corn crop in 1991 from the cover crop was calculated as the difference between the biomass nitrogen content in the corn plots that had a cover crop and the nitrogen content of the corn in the check plots (no cover crop).

3.2.2 Soil sampling and analysis

Soil sampling was done twice in the fall of 1990 and three times in the spring of 1991. The samples were taken to a depth of 60 cm in four depth increments (0-15, 15-30, 30-45 and 45-60 cm) in the fall and in the first sampling of the spring. Sampling on the final sampling date in the spring was done only to 45 cm in three depth increments due to sampling difficulty. The samples were analyzed for nitrate and ammonium concentrations by the Analytical Services Laboratory in the Dept. of Land Resource Science. Ammonium, nitrate and mineral (NH_4 + NO_3) N contents in the upper 45 cm of the soil profile were calculated assuming 2,000,000 kg of oven dry soil per hectare.

3.2.3 Soil solution sampling and analysis

One soil solution collection tube was placed at a depth of 75 cm in each of the plots. Samples were taken four times, for wheat and barley, and twice for the corn plots in the fall of 1990. A further sampling was done in the spring of 1991. The samples were analyzed for nitrate and ammonium concentrations.

3.3 Results

3.3.1 Cover Crop Biomass and N and P Contents

The mean values of biomass produced by each cover crop/N rate combination are presented in tabular form in Appendix A and graphically in the following sections. The mean concentrations of N and P in the biomass at each sampling time are presented in Appendix B. The biomass and N and P concentrations for each plot were used to calculate the biomass N and P contents presented graphically in the following sections.

3.3.1.1 Following barley at Ayr

Ryegrass, oilseed radish and red clover samples were taken on September 25, October 23 and November 13 to provide estimates of growth and uptake of N and P during the fall period.

The only significant difference in biomass accumulation in September was due to cover crops, (Figure 3.1); the growth of ryegrass was least and red clover was greatest. By November 13, the growth of oilseed radish and red clover was about 3000 kg dry biomass /ha whereas about 1000 kg dry biomass /ha accumulated with the ryegrass cover crop.

N accumulation or content depended on both cover crop and the N applied to the previous barley crop at both the September 25 and October 23 samplings. Although the N level x C interaction effect was significant, the reason is not readily obvious in Figure 3.2. By the November sampling, the only significant effect was due to cover crops (Fig.3.2). The quantity of N accumulated was least with ryegrass and greatest with red clover.

A significant N level x cover crop interaction effect occurred with biomass P at the September 25 sampling. The P content did not change with N level with the ryegrass and oilseed cover crops but decreased as the N level increased with the red clover cover crop (Fig.3.3). The oilseed radish crop absorbed much greater quantities of P than the other crops by the October and November sampling times (Fig. 3.3). The differences due to N levels at these sampling times, though significant were small.

3.3.1.2 Following barley at Woodstock

At the first sampling on September 24, only the cover crop effect was significant. The red clover biomass was higher than that for the other crops (Fig. 3.4). At both subsequent samplings on October 23 and November 13, only the N level effect was significant. It appears that the biomass produced at the recommended N level (N2) was lower than that at the N3 level (Fig. 3.4). In general the biomass produced at the Woodstock site was lower than that at the Ayr site. The ryegrass biomass production was similar to that for the other cover crops in contrast with the Ayr site.

There was a significant N level x cover crop interaction effect with the biomass N variable on September 24 and October 23 (Fig. 3.5). At the September 24 sampling time, biomass N decreased with increasing N level with red clover but increased with oilseed radish (Fig. 3.5). On October 23, the biomass N for oilseed radish decreased and then increased with increasing N level while that for ryegrass increased slightly and for red clover remained the same (Fig. 3.5).

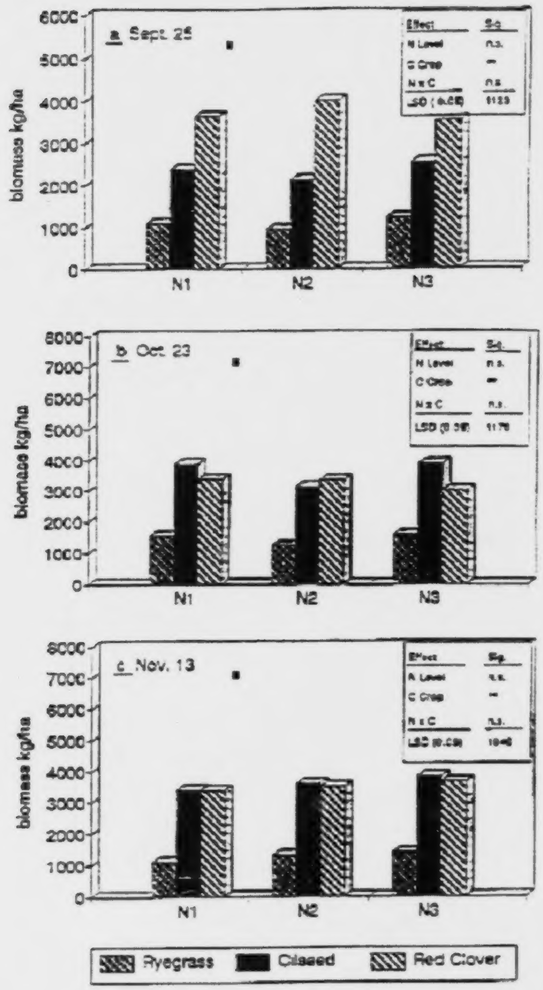


Fig. 3.1 Dry biomass yields of cover crops following barley at three N levels at the Ayr site.

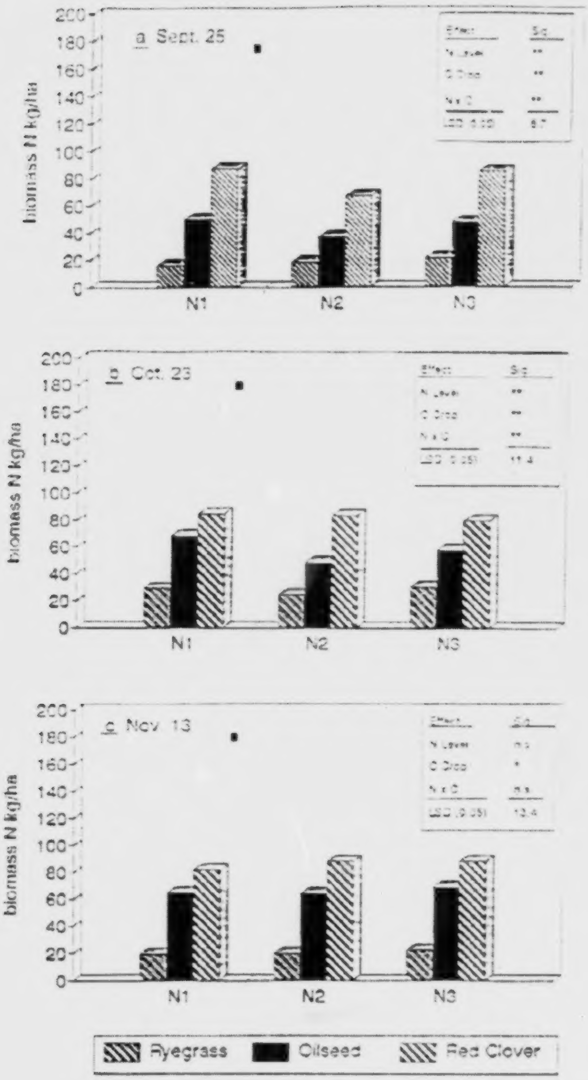


Fig. 3.2 **Biomass N content of three cover crops following barley at three N levels at the Ayr site.**

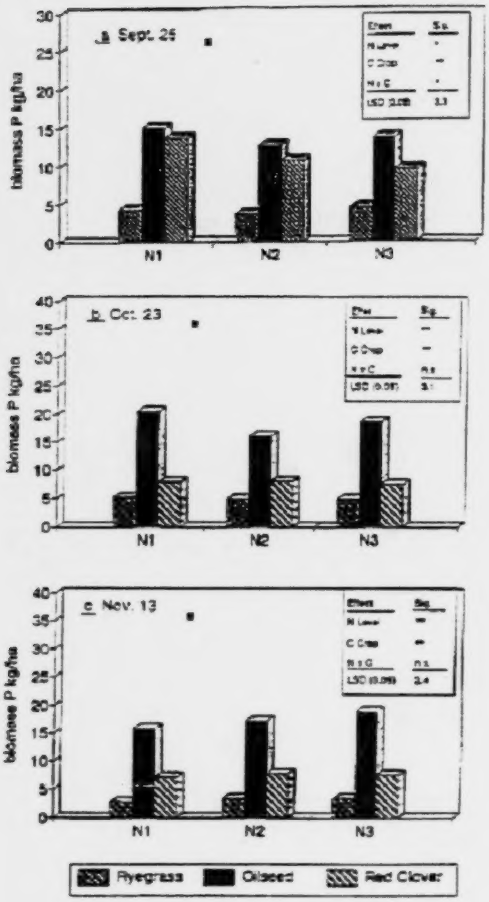


Fig. 3.3 Biomass P content of three cover crops following barley at three N levels at the Ayr site.

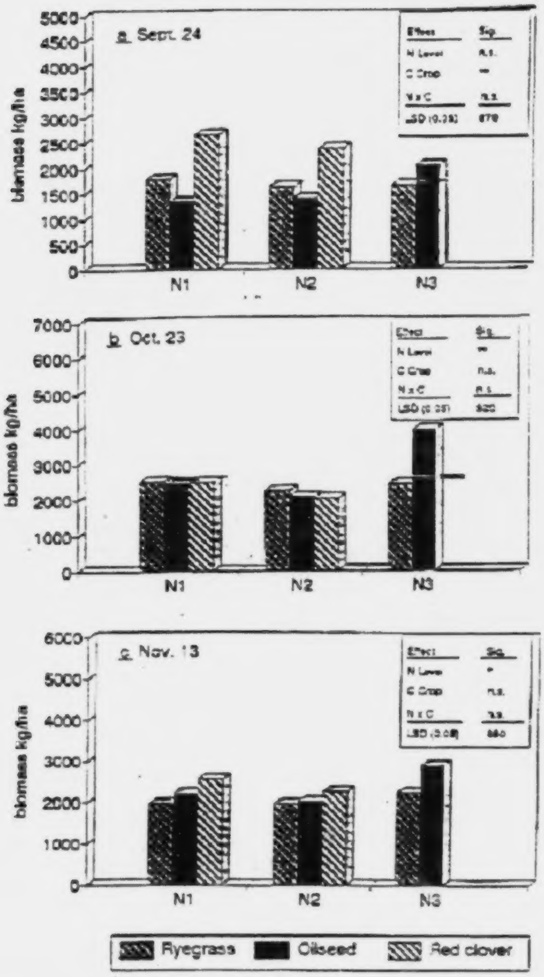


Fig. 3.4 Dry biomass yields of cover crops following barley at three N levels at the Woodstock site.

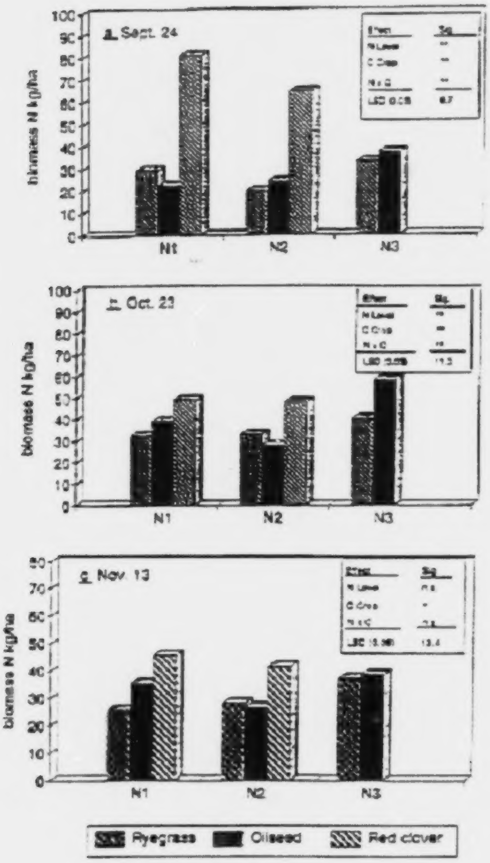


Fig. 3.5 **Biomass N content of three cover crops following barley at three N levels at the Woodstock site.**

The biomass N for the red clover was generally greater than that for ryegrass or oilseed radish at the N2 and N3 levels.

A significant N level x cover crop interaction effect occurred with biomass P content at the September 24 and October 23 samplings (Fig. 3.6). The biomass P increased with N level for oilseed radish but did not change for ryegrass or red clover at the September 24 sampling time (Fig. 3.6). At the

October 23 sampling, the biomass P decreased and then increased with increasing N levels with oilseed radish but did not change for the other cover crops. The oilseed radish contained the highest biomass P on November 13. There was a slightly higher biomass P content with the N3 level (Fig. 3.6).

3.3.1.3 Following winter wheat at Ayr

There were significant differences in cover crop biomass at the September 26 sampling time with ryegrass having produced the least and red clover the most biomass (Fig. 3.7). A significant N level x cover crop interaction effect occurred at the October 23 and November 14 sampling times (Fig. 3.7). On both dates the red clover biomass did not change while oilseed radish yield increased with increasing N level.

The biomass N content generally increased with N level at the October 23 sampling while there were significant differences with cover crops (Fig. 3.8). Ryegrass contained the least N while the red clover crop contained the most N. This trend continued to the October 23 and November 14 samplings except that the N content of oilseed radish became similar to that for red clover with the N3 level (Fig. 3.8). The biomass N content of ryegrass and red clover did not change with N level whereas that of oilseed radish increased with increasing N level.

The biomass P content was significantly lower for ryegrass than oilseed radish and red clover at the September 26 sampling (Fig. 3.9). The biomass P content of oilseed radish increased with increasing N levels at the October 23 and November 14 samplings while that for ryegrass and red clover changed relatively little thus accounting for a significant N level x cover crop interaction effect (Fig. 3.9). The P content of the oilseed radish was generally greater than the other two cover crops reflecting a high P concentration in the crop.

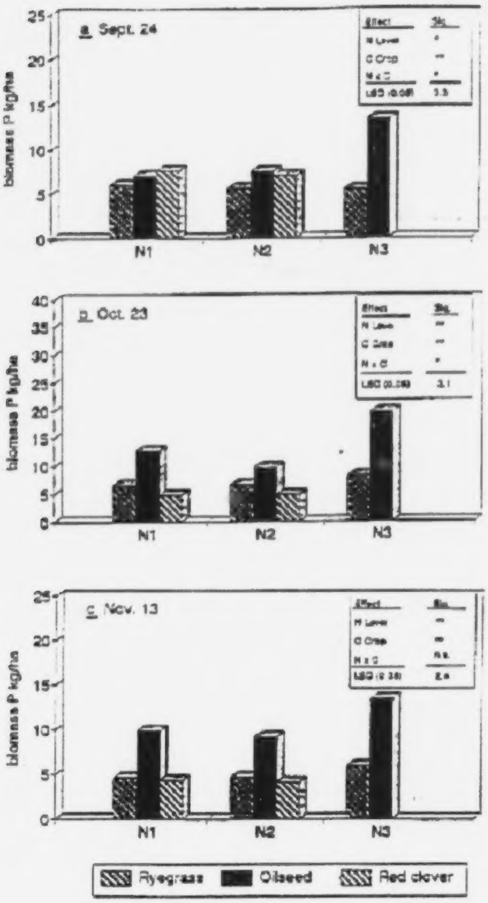


Fig. 3.6 Biomass P content of three cover crops following barley at three N levels at the Woodstock site.

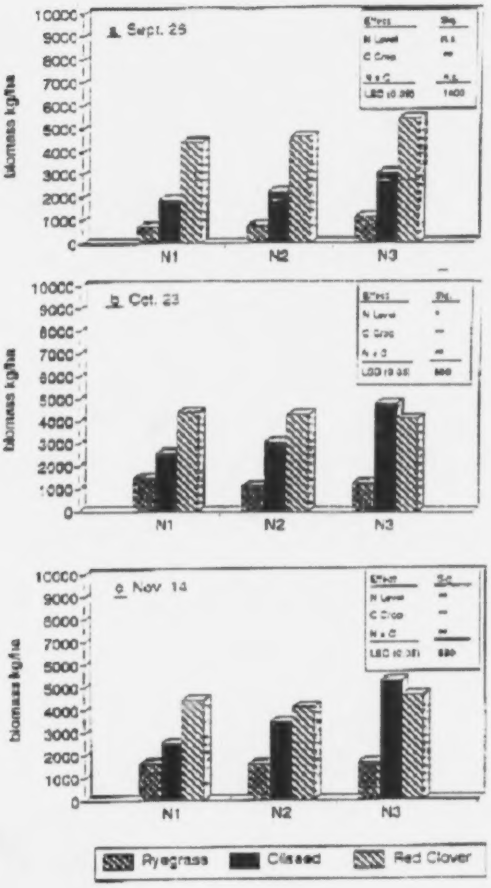


Fig. 3.7 Dry biomass yields of three cover crops following winter wheat at three N levels at the Ayr site.

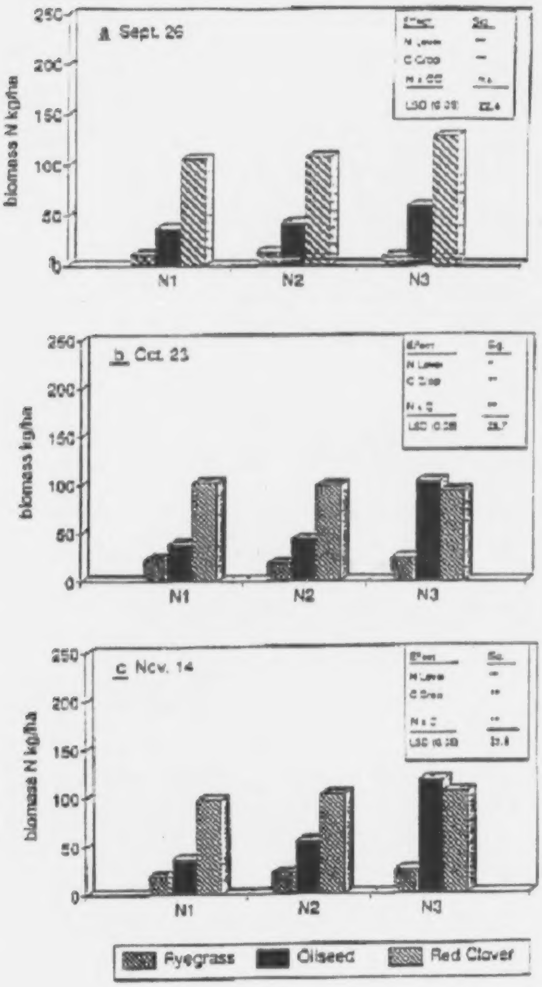


Fig. 3.8 Biomass N content of three cover crops following winter wheat a three N levels at the Ayr site.

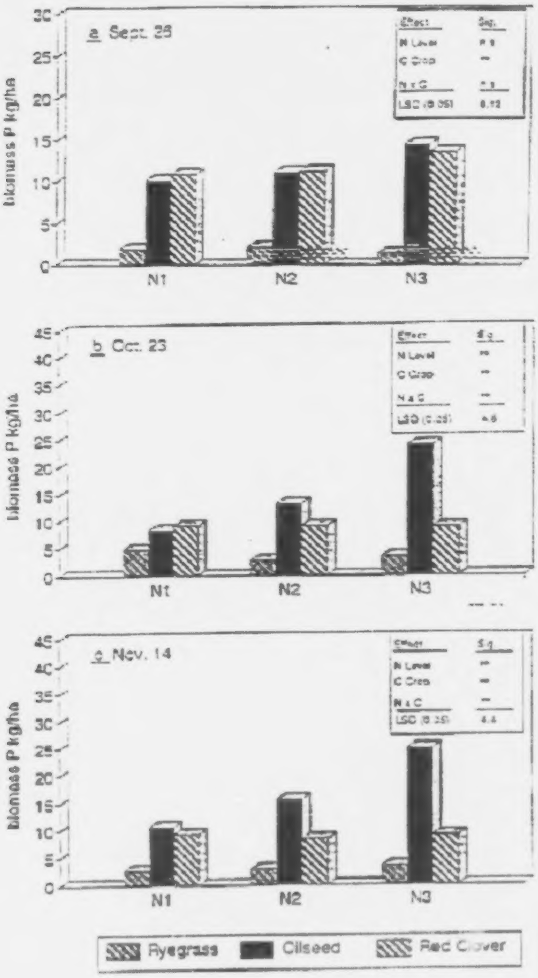


Fig. 3.9 Biomass P content of three cover crops following winter wheat at three N levels at the Ayr site.

3.3.1.4 Following winter wheat at Woodstock

Oilseed radish biomass was lower than for the other crops at the September 18 sampling (Fig. 3.10). There were no significant treatment effects at the October 22 sampling time. By the November 13 sampling, oilseed radish biomass had responded to increasing N levels especially N3 whereas ryegrass and red clover biomass yields did not differ with N level (Fig.3.10).

The only significant effects with biomass N occurred with the September 18 sampling (Fig. 3.11). Biomass N increased with increasing N levels at the September 18 sampling. Also biomass N in red clover was greater than the other cover crops at this sampling time.

Biomass P decreased and then increased with increasing N levels at the September 18 and November 13 samplings (Fig. 3.12). Although a significant N level x cover crop interaction effect did not occur, this trend appeared to be more evident with the oilseed radish crop. The oilseed radish crop had the highest contents of P at all three sampling dates.

3.3.1.5 Comparisons of cover crop responses following barley at the Ayr and Woodstock sites

Comparisons amongst cover crops and sites can not be tested statistically. However, some differences are evident.

Response to N at Ayr was generally greater following winter wheat than barley (Figs. 3.1 and 3.7). This was not evident at the Woodstock site (Fig. 3.4 and 3.10). Cover crop biomass following barley at Ayr appeared to be higher than that at Woodstock (Fig. 3.1 and 3.4). This was not evident following winter wheat. Ryegrass growth at Ayr was less than growth of the other cover crops following both barley and winter wheat (Figs. 3.1 and 3.7) whereas yields of all cover crops were similar at Woodstock (Figs. 3.4 and 3.10).

Biomass N content at Ayr increased from the ryegrass to the oilseed radish to the red clover cover crops (Figs. 3.2 and 3.8) but this trend was not evident at the Woodstock site (Figs. 3.5 and 3.11). The N level effect occurred only with the oilseed radish crop following winter wheat at the Ayr site.

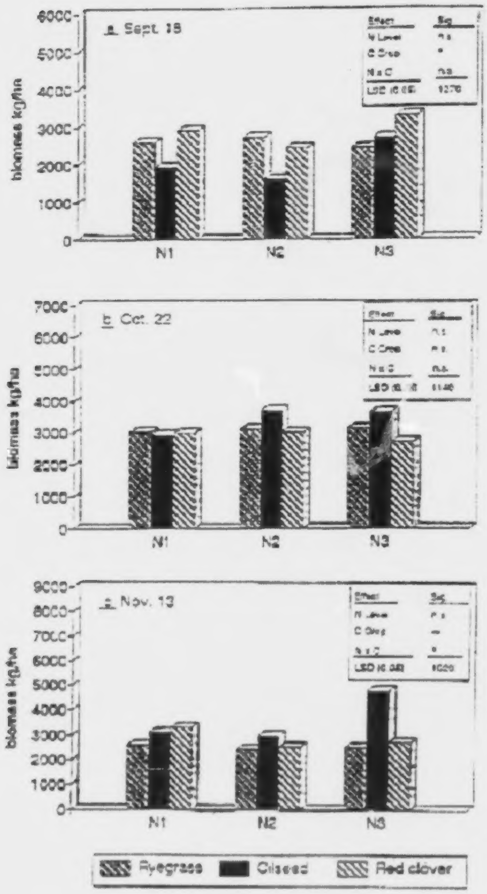


Fig. 3.10 Dry biomass yields of three cover crops following winter wheat at three N levels at the Woodstock site

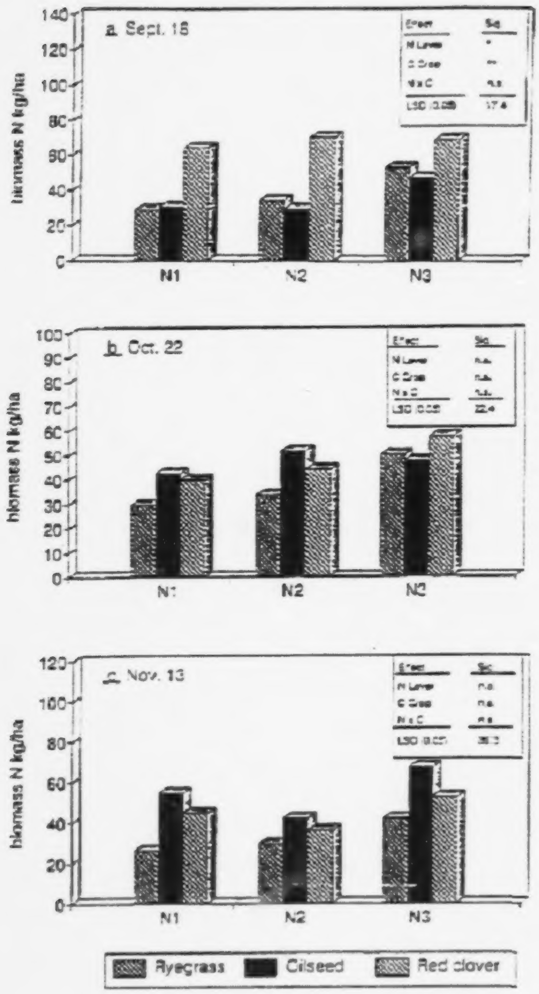


Fig. 3.11 Biomass N content of three cover crops following winter wheat at three N levels at the Woodstock site

Fig. 3.12 Biomass P content of three cover crops following winter wheat at three N levels at the Woodstock site

In almost all cases, biomass P content was greatest with the oilseed radish crop. Biomass P content in red clover was greater than in ryegrass for both cereal crops at Ayr probably reflecting biomass yields (Figs. 3.3 and 3.9)

3.3.2 Mineral N contents of soil under cover crops following barley, winter wheat and corn

The NH_4^+ and NO_3^- concentrations in soils at different depths under the different cover crop/N rate combinations at each sampling are presented in Appendix C. A study of the data revealed that the differences in concentrations with depth were small, often difficult to interpret, and of little practical significance in determining the effects of cover crops. It was concluded that the NH_4^+, NO_3^- and mineral N (NH_4 + NO_3) contents in the soil profile at different dates and under different cover crops would be more meaningful for the purposes of this project. These data are presented in the following sections.

3.3.2.1 Following barley

The NH_4^+, NO_3^- and mineral (NH_4^+ + NO_3^-) contents in the 0-45 cm soil layer with various cover crops after barley are shown in Fig. 3.13 for Ayr and Fig. 3.14 for Woodstock.

In general, NH_4^+ levels were least affected by the cover crop treatments (Fig. 3.13 and 3.14). There was a decrease in NH_4^+ content during the fall months at Woodstock but not at Ayr. In the spring months, there was a decrease followed by an increase at Ayr whereas, at Woodstock, an increase occurred in May followed by a decrease.

The three cover crops significantly decreased the NO_3^- contents in September but not in November (Fig. 3.13 and 3.14). The NO_3^- content was particulary low at Woodstock in November.

A release of N from the oilseed radish cover crop apparently occurred by the April sampling and persisted into May (Fig. 3.13 and 3.14). By the June sampling, however, the greatest release of N occurred with the red clover crop.

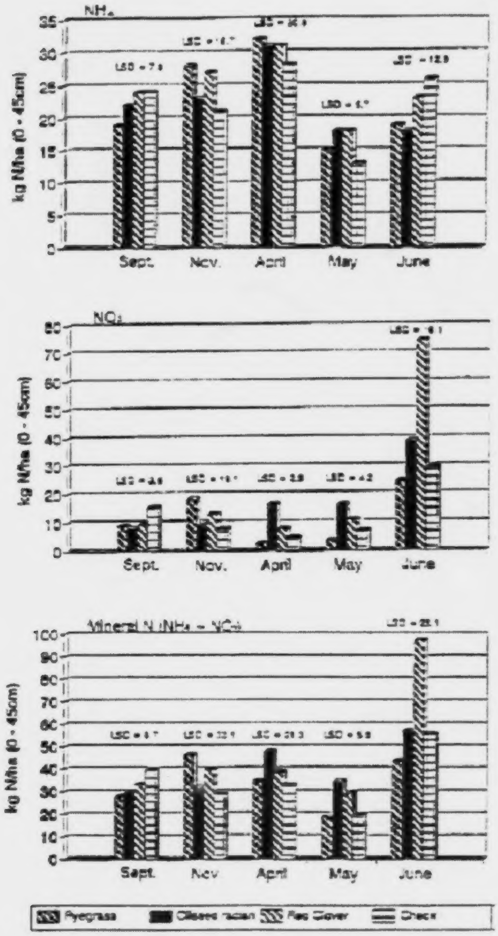


Fig. 3.13 Ammonium, nitrate and mineral N contents to the 45 cm depth with cover crops at samplings in the fall (1990) and spring (1991) following barley at the Ayr site

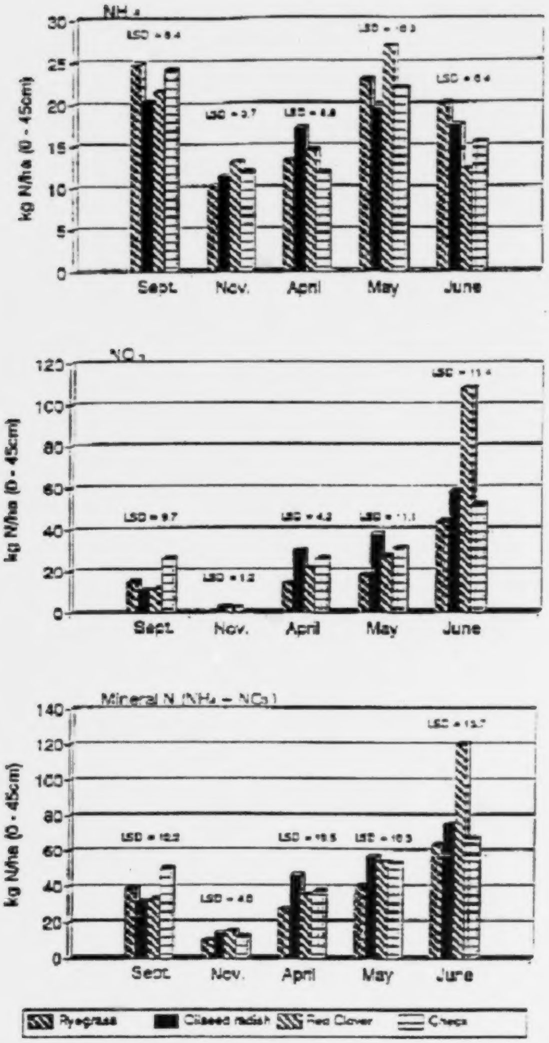


Fig. 3.14 Ammonium, nitrate and mineral N contents to the 45 cm depth with cover crops at samplings in the fall (1990) and spring (1991) following barley at the Woodstock site

The increased NO_3^- present was derived from NH_4^+ which, in turn, was released from cover crop residues by microbial processes. By the June sampling, the NO_3^- content on the oilseed radish plots was not significantly different than that from the soil itself (check treatment). There was a tendency for lower NO_3^- content with the ryegrass cover crop treatment compared with the check treatment suggesting that mineral N immobilization occurred.

The mineral N contents in the 0-45 cm layer also support the conclusion that, by June, N release from ryegrass and oilseed radish residues was not different than that from soil without a cover crop. The greatest release occurred with the red clover treatment.

3.3.2.2 Following winter wheat

The winter wheat crop at Ayr inadvertently received a manure application during the winter period thereby rendering this experiment useless for further study. Thus only the NH_4^+ and NO_3^- contents for the fall period at Ayr will be discussed.

Soil NH_4^+ contents were not affected by cover crops at Ayr but a substantial decrease occurred from the September to November sampling (Fig. 3.15). The NO_3^- content was significantly lower with the cover crop treatments in September especially with oilseed radish (Fig. 3.15). By November, however, NO_3^- content was lowest with the ryegrass cover crop. There was an overall but small decrease in mineral N with the cover crops at the September sampling but not at the November sampling.

In September and November at Woodstock, NH_4^+ content tended to be slightly higher with the oilseed radish and red clover cover crops (Fig 3.16). In the spring months, cover crop treatments had little effect on NH_4^+ content. The most obvious change was the increase in NH_4^+ content with all cover crops from the May to June samplings.

The soil NO_3^- content decreased from September to November at Woodstock (Fig. 3.16). There was a tendency for the NO_3^- content to be slightly higher in September with the red clover and no cover crop treatments.

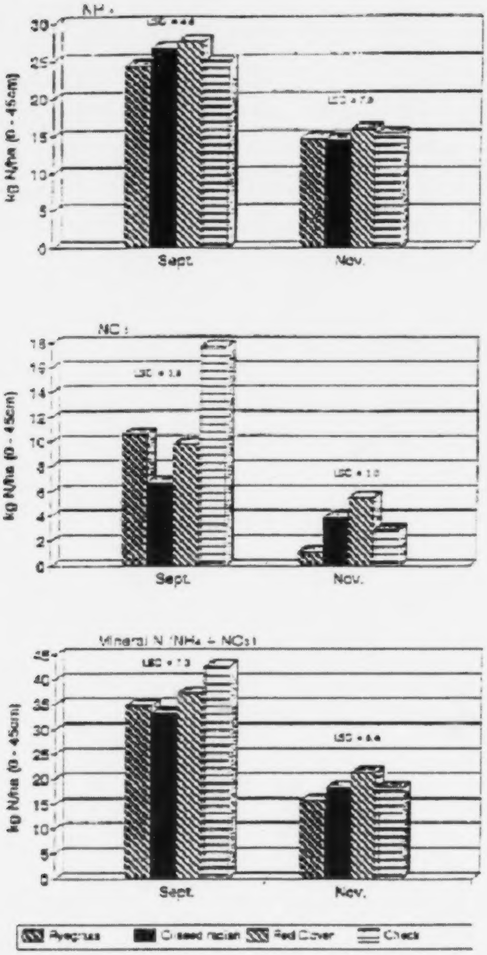


Fig. 3.15 Ammonium, nitrate and mineral N contents to the 45 cm depth with cover crops at samplings in the fall (1990) following winter wheat at the Ayr site

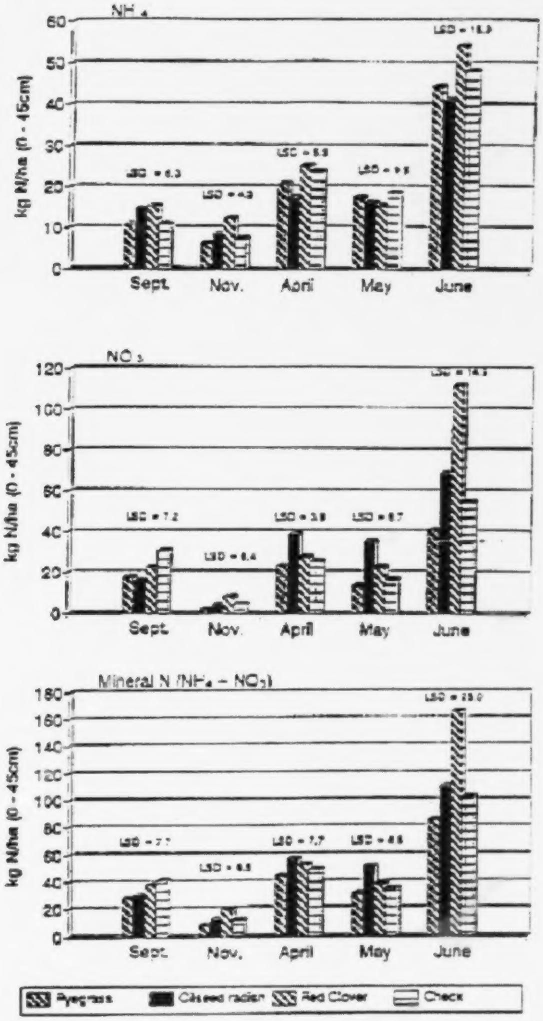


Fig. 3.16 Ammonium, nitrate and mineral N contents to the 45 cm depth with cover crops at samplings in the fall (1990) and spring (1991) following winter wheat at the Woodstock site

Soil NO_3^- content was highest with oilseed radish in April and May (Fig. 3.16). By the June sampling, however, a much greater production of NO_3^- had occurred with the red clover cover crop along with some further NO_3^- production with the oilseed radish crop. It is noteworthy that the soil NO_3^- content following the ryegrass cover crop was lower than that with the no cover crop treatment especially at the June sampling. Thus, NO_3^- production occurred relatively early (in April) following oilseed radish but was exceeded by production from the red clover cover crop residues by the June sampling. On the other hand, NO_3^- or mineral N immobilization probably occurred following the ryegrass cover crop. It is noteworthy that the NH_4^+ content of the soil was relatively high at the June sampling. This suggests that nitrification had not reached its full potential.

The soil mineral N contents (Fig. 3.16) generally reflect the NH_4^+ and NO_3^- contents.

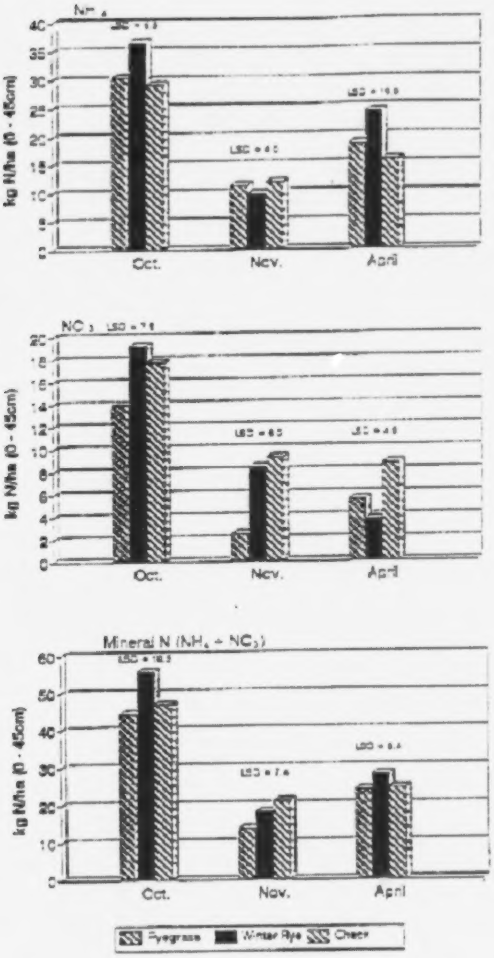
3.3.2.3 Following corn

The NH_4^+ ,NO_3^- and mineral N contents (0-45 cm) for October, November and April are presented in Fig. 3.17 to 3.18. In few cases did cover crops affect soil N content probably because of poor establishment. There was a general decrease in both forms of N from October to November indicating leaching and/or denitrification losses. In most cases, the contents were about the same at the April sampling.

The levels of mineral N were generally very high in October following corn especially at the Woodstock site. The contents following barley and winter wheat were about 30-35 kg N/ha in September and decreased to about 10-20 kg N/ha by November. The decreases with corn were particularly large during this period at the Woodstock site (120 to 40 kg N/ha).

3.3.3 Nitrate and ammonium concentrations in soil solution below cover crops

Soil solution samples were taken at the 75 cm depth to measure NH_4^+ and NO_3^- concentrations. The objective was to monitor the concentrations of these ions moving in the soil solution from the root zone into the groundwater.



ig. 3.17 Ammonium, nitrate and mineral N contents to the 45 cm depth with cover crops at samplings in the fall (1990) and spring (1991) following corn at the Ayr site.

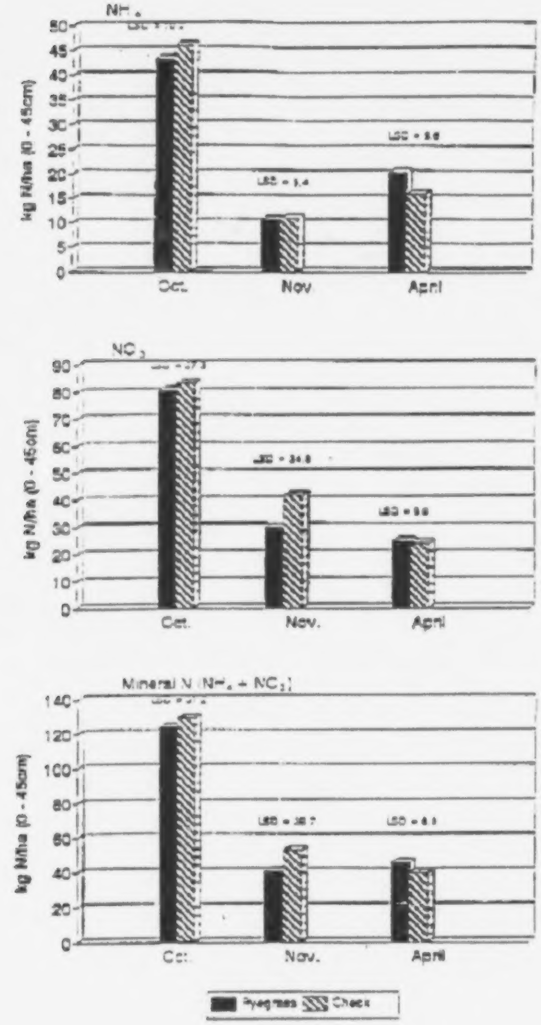


Fig. 3.18 Ammonium, nitrate and mineral N contents to the 45 cm depth with cover crops at samplings in the fall (1990) and spring (1991) following corn at the Woodstock site.

Soil solutions were not always obtained from the samplers because of low soil moisture content. Accordingly, because of missing data it was not possible to analyse the data statistically. Nevertheless, the mean values are presented along with comments. The rate of N applied to the main crop had no influence on NH_4^+ and NO_3^- concentrations in the soil solution. The values presented are means for the three N rates and three replicates. Thus there should have been 9 samples at each sampling date for each cover crop treatment. The number of samples actually obtained are indicated in parentheses with each datum in the following Tables. Samples were taken only from plots with significant cover crop establishment following the corn crop.

3.3.3.1 Ammonium concentrations

As expected, NH_4^+ concentrations were generally lower than one mg N/L. There were no apparent trends related to cover crop treatments (Tables 3.1 to 3.6). It appeared, however, that NH_4^+ concentrations were highest during November. Samples could not be extracted at the Ayr site in late April.

3.3.3.2 Nitrate concentrations

At the Ayr site, NO_3^- concentration appeared to be relatively high with the red clover and no cover crop treatments following cereal crops (Tables 3.7 and 3.8) particularly in October but decreased rapidly particularly following barley. The NO_3^- concentrations with ryegrass and oilseed radish were lower than the accepted maximum value of 10 mg NO_3^- -N/L.

The NO_3^- concentrations were relatively low with all cover crop treatments at each sampling date at Woodstock (Tables 3.9 and 3.10). There was a somewhat higher NO_3^- concentration with the no cover crop treatment after winter wheat but the concentration was below 10 mg NO_3^--N/L (Table 3.10).

The NO_3^- concentrations were relatively high following corn at both sites (Tables 3.11 and 3.12) especially at Woodstock even with the April sampling. This is in contrast with those for barley and winter wheat. There is no obvious explanation for this difference. The amounts of NO_3^- in the soil profile (0-45 cm) following the cereal crops at Woodstock decreased markedly from October to November (Figs. 3.14 and 3.16). This disappearance of NO_3^- must have been due to one or a combination of three processes: (1) uptake by cover crops; (2) leaching to deeper depths; or (3) denitrification. Because the decrease on the check plot was similar to that on the cover crop plots, uptake by the cover crops can be ruled out as the sole cause. Because there was no increase in NO_3^- in soil solution at the 75 cm depth (Tables 3.9 and 3.10) leaching is not a likely explanation. Thus it can be concluded that the disappearance was probably due to denitrification. There was an above normal amount of rainfall in September and early October in 1990 which could have resulted in the denitrification. The soil on the corn plots would have been considerably drier at this time due to continued water extraction by the crop through September. Thus denitrification would have been less likely to occur.

Table 3.1: Concentrations of NH_4^+-N in the soil solution (75cm) with cover crop treatments at different dates following barley at the Ayr site (1990)

Date	Annual Ryegrass	Oilseed Radish	Red Clover	Check
		(mg L^{-1})		
Oct. 13	0 (3)	0 (3)	0 (6)	0.1 (8)
Nov. 2	0.1 (1)	0.1 (4)	0.1 (2)	0 (6)
Nov. 19	0.2 (4)	0.4 (5)	0.2 (2)	0.1 (4)
Dec. 6	-	0.1 (1)	0 (3)	0.1 (3)

No. of observations for each value in parentheses.

Table 3.2: Concentration of NH_4^+-N in the soil solution (75 cm) with cover crop treatments at different dates following winterwheat at the Ayr site (1990)

Date	Annual Ryegrass	Oilseed Radish	Red Clover	Check
		(mg L^{-1})		
Oct. 3	0 (3)	0.2 (6)	1.3 (6)	1.2 (2)
Nov. 1	0 (6)	0.2 (7)	0.4 (4)	1.9 (3)
Nov. 19	0.1 (6)	0.1 (8)	0.2 (7)	0.1 (3)
Dec. 6	0 (5)	0 (3)	0 (6)	0.1 (2)

No. of observations for each value in parentheses.

Table 3.3: Concentration of NH_4^+-N in the soil solution (75 cm) with cover crop treatments at different dates following barley at the Woodstock site (1990-91)

Date	Annual Ryegrass	Oilseed Radish	Red Clover	Check
	(mg L^{-1})			
Oct. 12	0 (8)	0.1 (7)	0 (3)	0 (2)
Oct.31	0.2 (7)	0.4 (7)	0 (3)	0.1 (7)
Nov. 22	0.2 (8)	0.1 (8)	0.2 (4)	0.1 (7)
Dec.6	0 (8)	0 (8)	0 (4)	0 (9)
April 29	0 (8)	0 (8)	0 (4)	0 (9)

No. of observations for each value in parentheses.

Table 3.4: Concentration of NH_4^+-N in the soil solution (75 cm) with cover crop treatments at different dates following winterwheat at the Woodstock site (1990-91)

Date	Annual Ryegrass	Oilseed Radish	Red Clover	Check
	(mg L^{-1})			
Oct. 11	0 (8)	0.4 (8)	0 (6)	0 (7)
Oct. 31	0.1 (7)	1.3 (8)	0.1 (5)	0.1 (8)
Nov. 20	0.1 (7)	1.2 (8)	0.3 (7)	0.2 (9
Dec. 6	0 (8)	0.4 (7)	0 (6)	0 (9)
April 29	0 (7)	0.1 (6)	0.2 (7)	0.1 (9)

No. of observations for each value in parentheses.

Table 3.5: Concentration of NH_4^+-N in the soil solution (75 cm) with cover crop treatments following corn at the Ayr site (1990)

Date	Annual Ryegrass	Winter Rye	Check
	(mg L^{-1})		
Nov. 21	0 (7)	0 (8)	0 (8)

No. of observations for each value in parentheses.

Table 3.6: Concentration of NH_4^+-N in the soil solution (75 cm) with cover crop treatments at different dates following corn at the Woodstock site (1990-91)

Date	Winter Rye	Check
	(mg L^{-1})	
Nov. 21	0 (9)	0 (7)
Dec. 6	0 (8)	0 (5)
April 30	0 (8)	0 (8)

No. of observations for each value in parentheses

Table 3.7: Concentration of NO_3^--N in the soil solution (75 cm) with cover crop treatments at different dates following barley at the Ayr site (1990)

Date	Annual Ryegrass	Oilseed Radish	Red Clover	Check
		(mg L^{-1})		
Oct. 3	3 (3)	10 (3)	54 (6)	43 (8)
Nov. 2	1 (1)	0 (4)	12 (2)	14 (6)
Nov. 19	1 (4)	2 (5)	16 (2)	4 (4
Dec. 6	-	0 (1)	2 (6)	2 (3

No. of observations for each value in parentheses.

Table 3.8: Concentration of NO_3^--N in the soil solution (75 cm) with cover crop treatments at different dates following winterwheat at the Ayr site (1990)

Date	Annual Ryegrass	Oilseed Radish	Red Clover	Check
		(mg L^{-1})		
Oct. 3	5 (3)	9 (6)	29 (7)	43 (2)
Nov. 1	7 (6)	3 (7)	21 (4)	21 (3)
Nov. 19	2 (6)	0 (8)	10 (7)	14 (3)
Dec. 6	4 (5)	1 (3)	10 (6)	21 (2)

No. of observations for each value in parentheses.

Table 3.9: Concentration of NO_3^--N in the soil solution (75 cm) with cover crop treatments at different dates following barley at the Woodstock site (1990-91)

Date	Annual Ryegrass	Oilseed Radish	Red Clover	Check
	(mg L^{-1})			
Oct. 12	1 (8)	0 (7)	0 (3)	2 (7)
Oct. 31	0 (7)	0 (7)	0 (3)	1 (7)
Nov. 22	0 (8)	0 (8)	1 (4)	0 (7)
Dec. 6	0 (8)	0 (8)	0 (4)	0 (9)
April 29	1 (8)	4 (8)	4 (4)	3 (9)

No. of observations for each value in parentheses.

Table 3.10: Concentration of NO_3^--N in the soil solution (75 cm) with cover crop treatments at different dates following winterwheat at the Woodstock site (1990-91)

Date	Annual Ryegrass	Oilseed Radish	Red Clover	Check
	(mg L^{-1})			
Oct. 11	1 (8)	1 (8)	2 (6)	6 (7)
Oct. 31	0 (7)	3 (8)	1 (5)	2 (8)
Nov. 20	0 (7)	0 (8)	1 (7)	4 (9)
Dec. 6	0 (8)	0 (7)	1 (6)	4 (9)
April 29	0 (7)	4 (6)	4 (7)	3 (8)

No. of observations for each value in parentheses.

Table 3.11: Concentration of NO_3^--N in the soil solution (75 cm) with cover crop treatments following corn at the Ayr site (1990)

Date	Annual Ryegrass	Winter Rye	Check
	(mg L^{-1})		
Nov. 21	36 (7)	37 (8)	39 (8)

No. of observations for each value in parentheses.

Table 3.12: Concentration of NO_3^--N in the soil solution (75 cm) with cover crop treatments at different dates following corn at the Woodstock site (1990-91)

Date	Winter Rye	Check
	(mg L^{-1})	
Nov. 21	29 (9)	25 (7)
Dec. 6	23 (8)	19 (5)
April 30	15 (8)	14 (8)

No. of observations for each value in parentheses

3.3.4 Response and N recovery by corn from previous cover crops

Corn plants were harvested in late June and early August to determine biomass and biomass N contents in response to previous cover crops. The general objective was to determine the release of N conserved in the cover crops to the following crop.

3.3.4.1 From cover crops following Barley

A significant cover crop effect occurred at Ayr only with the June 21 sampling (Fig. 3.19) and was likely due to lower biomass yields with the oilseed radish cover crop.

There were significant cover crop differences in biomass N content at both sampling dates (Fig. 3.20). Red clover resulted in the highest biomass N content at both sampling dates. The biomass N content was generally lowest with the ryegrass cover crops and tended to be lower than that for the check treatment (no cover crop) at the August 1 sampling.

Biomass yields at Woodstock were generally lower with ryegrass than any of the other cover crop treatments or the check at both the June 19 and August 6 samplings (Fig. 3.21).

Coinciding with low biomass yields, the biomass N content was also lowest with the ryegrass cover crop at both sampling dates (Fig. 3.22). A significant N level x cover crop interaction effect occurred with the August 6 sampling probably due mostly to increasing biomass N with increasing N levels

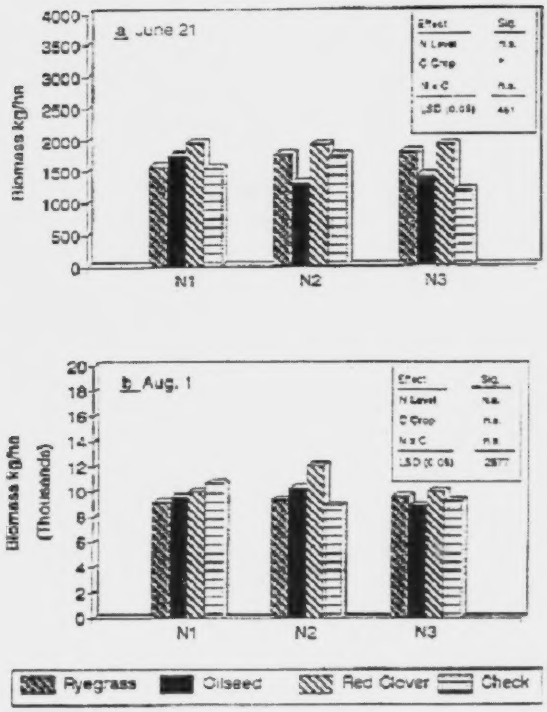


Fig. 3.19 Dry biomass yield of corn in June and August following different cover crops following barley at the Ayr site.

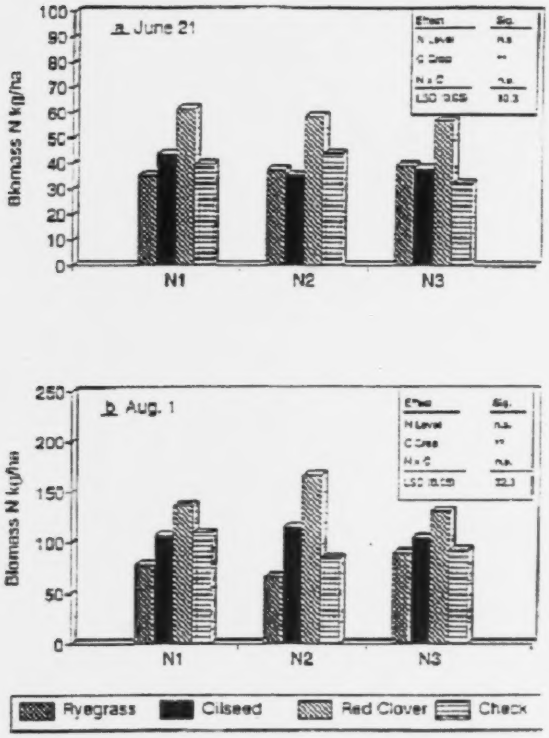


Fig. 3.20 Corn biomass N content in June and August following different cover crops following barley at the Ayr site.

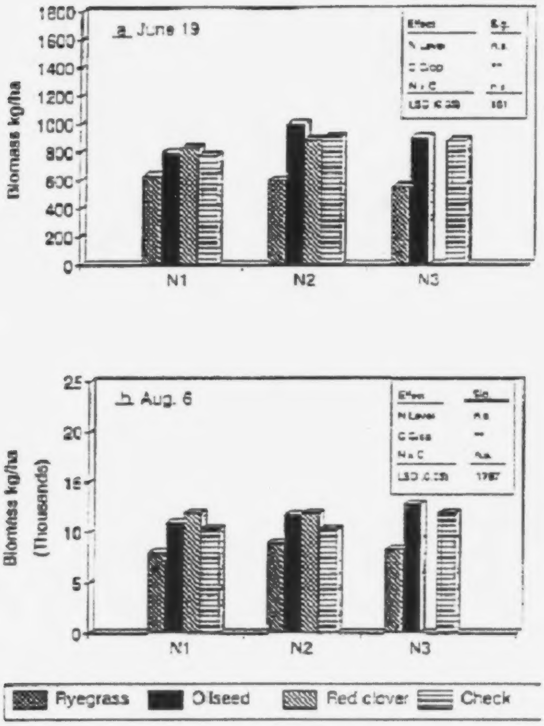


Fig. 3.21 Dry biomass yield of corn in June and August following different cover crops following barley at the Woodstock site.

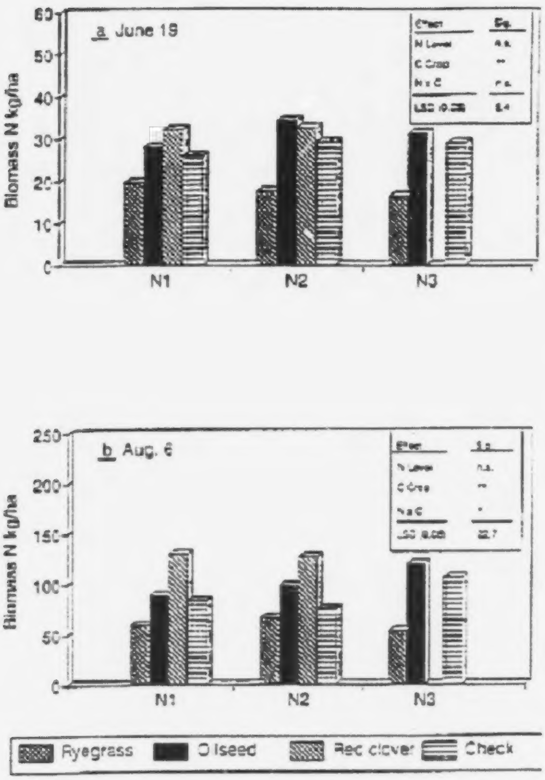


Fig. 3.22 Corn biomass N content in June and August following different cover crops and barley at the Woodstock site.

with the oilseed radish cover crop treatment. Also, the no cover crop treatment produced a higher biomass N with the N3 level.

3.3.4.2 From cover crops following winter wheat

The plots at Ayr were abandoned following an inadvertent manure application during the winter in 1991.

The corn biomass yield was lowest with ryegrass at both sampling dates (Fig. 3.23). There was also a tendency for yield to be slightly higher with the June 19 sampling following the oilseed radish cover crop.

Biomass N was significantly lower following the ryegrass cover crop at both sampling dates (Fig. 3.24).

3.3.4.3 From cover crops following corn

There were no significant effects of previous cover crop treatments where corn was the main crop in 1990. Cover crop establishment was poor at both sites. The corn biomass and biomass N data are included here for possible comparisons with those where barley and winter wheat were the main crops in 1990 (Fig. 3.25 to 3.28).

3.3.4.4 Summary of cover crop N benefits

The overall benefit or lack thereof of cover crop N to corn biomass N is shown in Fig. 3.29 for each sampling time following both cereal crops at both sites in 1991. The effects of cover crop treatments on dry biomass yields of corn in June and August are shown in Fig. 3.30. This provides an overall impression of the availability of cover crop N to the next crop although without the benefit of statistical analyses. The apparent gains or losses in corn biomass N with different cover crops are based on comparisons with corn biomass N content with the "no cover crop" treatment.

It is evident that ryegrass resulted in an overall decrease in available N compared with the no cover crop treatment. While there was some residual N available from the oilseed radish, the greatest quantity was available from the red clover cover crop. It would therefore appear that the ryegrass cover

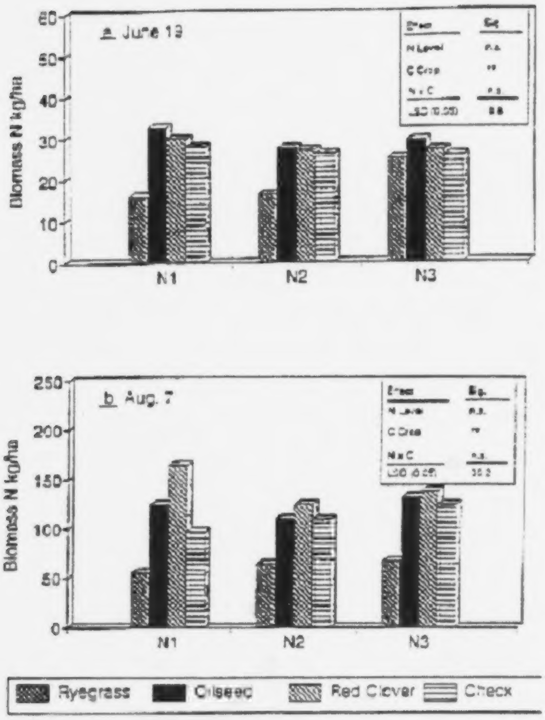


Fig. 3.23 Dry biomass yield of corn in June and August following different cover crops following winter wheat at the Woodstock site.

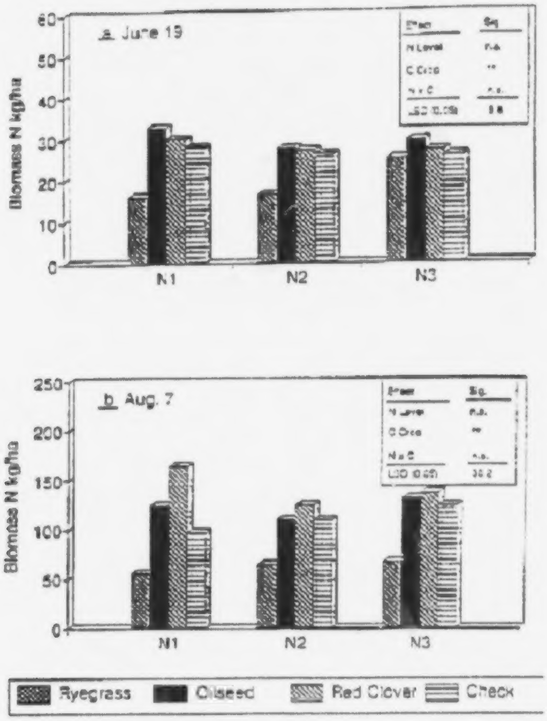


Fig. 3.24 Corn biomass N content in June and August following different cover crops following winter wheat at the Woodstock site.

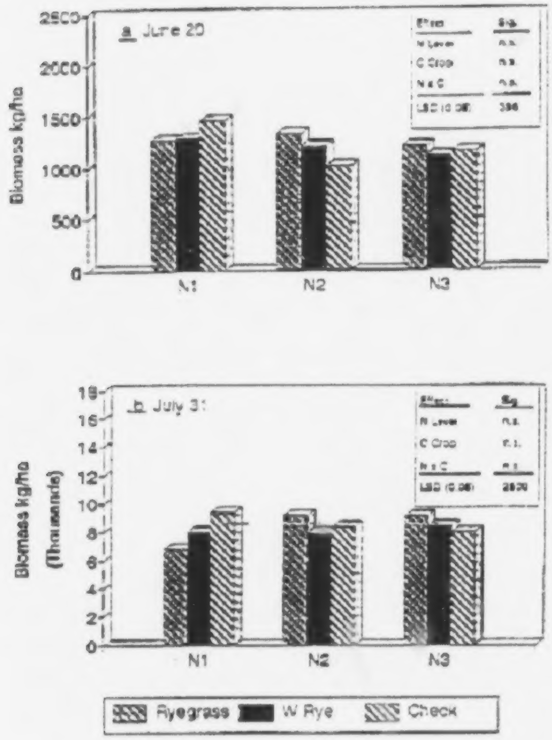


Fig. 3.25 Dry biomass yield of corn in June and July following different cover crops, following corn at the Ayr site.

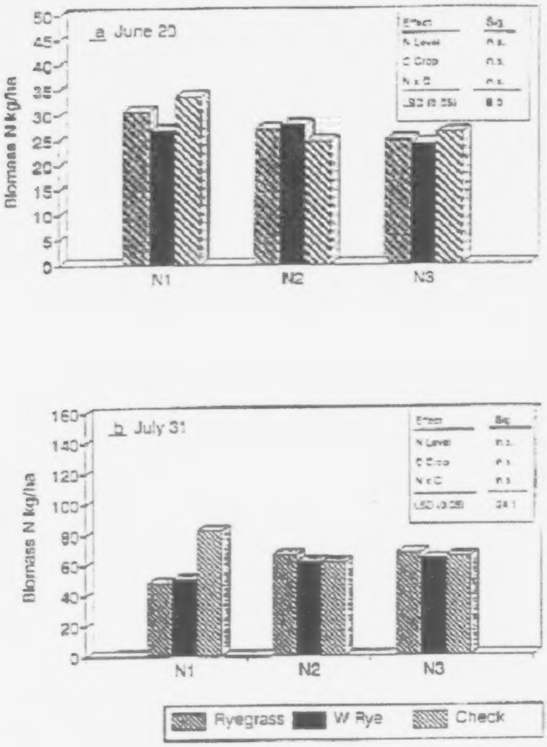


Fig. 3.26 Corn biomass N content in June and July following different cover crops following corn at the Ayr site.

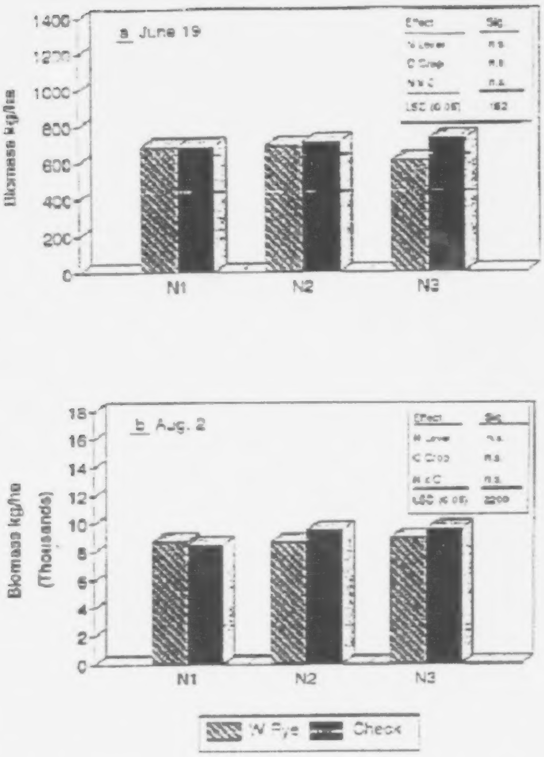


Fig. 3.27 Dry biomass yield of corn in June and August following cover crops following corn at the Woodstock site.

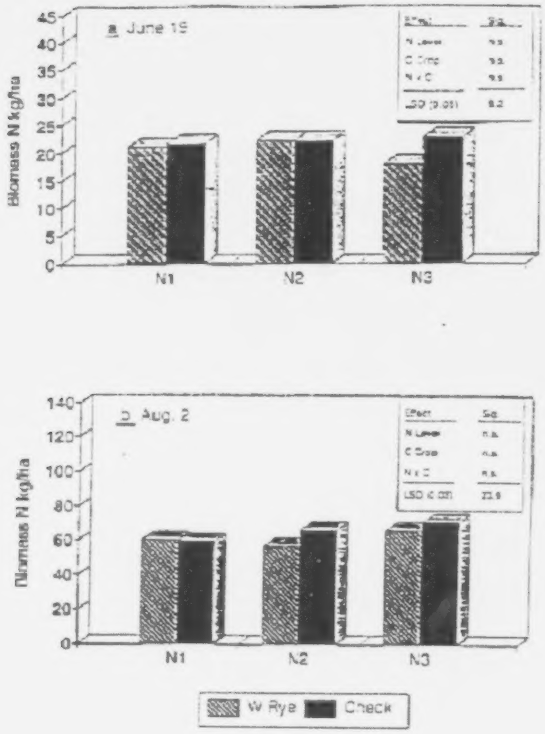


Fig. 3.28 Corn biomass N content in June and August following cover crops following corn at the Woodstock site.

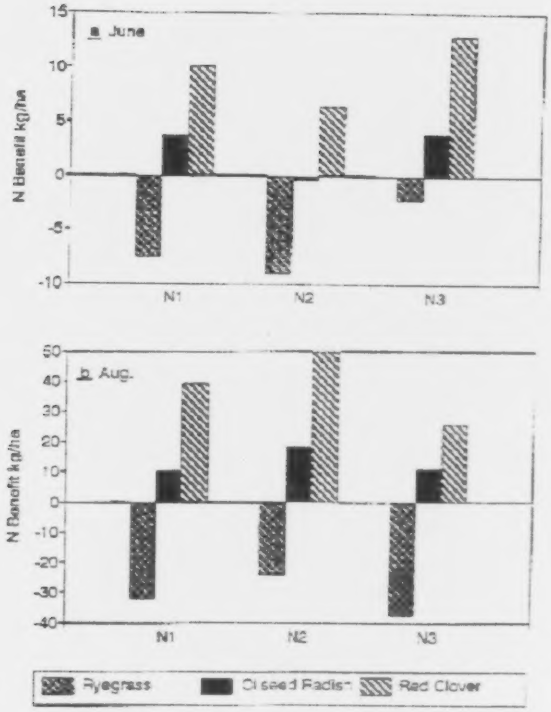


Fig. 3.29 Change in biomass N content of corn following different cover crops relative to the no cover crop treatment in June and August with different N levels (Average of both cereal crops at both sites).

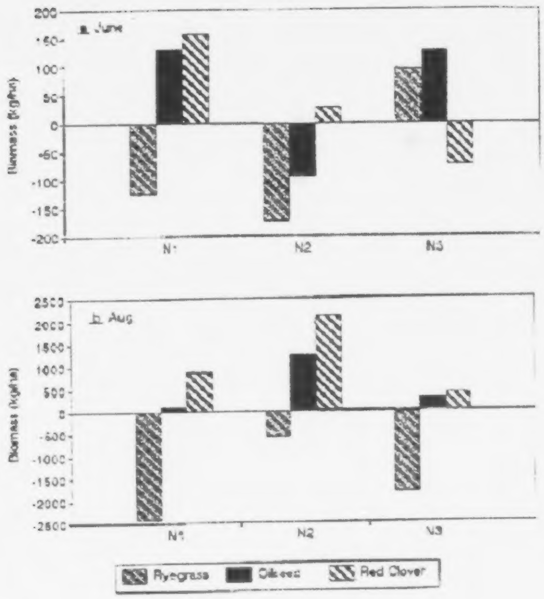


Fig. 3.30 Change in dry biomass of corn following different cover crops relative to the no cover crop treatment in June and August with different N levels at both sites (Average of both cereal crops at both sites).

crop resulted in a net immobilization of available N whereas red clover and probably oilseed radish resulted in a net mineralization or release of available N.

Generally, yields of corn biomass were lower following ryegrass and higher following oilseed radish or red clover. There were, however, some inconsistencies that are not explainable, especially ones related to different N levels applied to the previous crop.

These effects of cover crop on corn biomass and N content were also reflected in final grain yields as indicated in Section 2.4. Grain yields were greatest following red clover and least following ryegrass.

4.0 LEACHING OF NITROGEN AND PHOSPHORUS FROM COVER CROPS

4.1 Introduction

Cover crops have a number of potential beneficial effects including reduction of erosion, improvement of soil structure and prevention of leaching of nitrate-nitrogen. However, a potential detrimental effect of cover crops, either legume or nonlegume, on water quality does exist. It has been established that nutrients can be leached from the dead foliage and increase the concentration in runoff. This is of particular concern for phosphorus but also, to a lesser extent, for nitrogen. Any evaluation of the effectiveness of cover crops in reducing the impact of a cropping system on water quality must also consider this potential detrimental effect.

The quantity of a nutrient leached from plant material is dependent on four main factors: quantity of the nutrient present; mobility of the nutrient; solubility of the nutrient; and rainfall intensity and quantity (White, 1973; Schreiber and McDowell, 1985). The quantity of the nutrient present in the cells is related to the age, health, and nutrient supply to the plant (Tukey, 1971). Solubility of the nutrient is affected by the type of ion the nutrient is present in, the ambient temperatures, and stage of growth of the plant material (Tukey, 1971; White, 1973). The mobility of the nutrient is mainly affected by the health of the plant (Tukey, 1971). Plant health is determined by age and injury due to microorganisms, insects, physiological disorders, mechanical means and adverse climate (freezing, drying) (Tukey, 1971).

Natural conditions may subject plant material to drying and freeze-thaw cycles. Freezing of the cells disrupts cell membranes increasing the mobility of the nutrients (Timmons, et al. 1970). Timmons et al. (1970) found that freezing and thawing of alfalfa plant material increased the amount of inorganic P, organic P, and total N in leachate by factors of 46, 10, and 9 respectively over fresh plant leachates. These effects may not be as great if the plant material has lost much of its moisture before freezing. At lower moisture contents the cell membranes will not be disrupted as much by freezing

(White, 1973). The drying of the plant material itself may increase leaching of nutrients from plant material (Timmons, et al. 1970). Timmons et al. (1970) reported similar increases of organic P, inorganic P and total N in leachate from dried plant material as freezing and thawing over the leachate from fresh plant material.

Schreiber and McDowell (1985) studied the release of nutrients from wheat straw residues by leaching with simulated rainfall. They found that increasing rainfall intensity decreased concentrations of PO_4, NH_4, and organic carbon (OC) in leachate but NO_3 concentrations were unchanged. The decrease in nutrient concentration is attributed to a decrease in contact time between the water and plant material.

Schreiber (1985) studied the effect of loading rates (plant mass/area) on nutrient release by leaching. It was reported that increasing the loading rate curvilinearly increased both the concentration and total amount of PO_4, NH_4 and OC in leachate, but the nutrients lost per unit of plant material was decreased. Increased concentrations of nutrients in runoff at higher loading rates is associated with increased contact time between water and plant material, but nutrient loss per kg of plant material is greater at low loading rates due to the easier pathway of nutrients to runoff (Schreiber, 1985).

The mobility of nutrients, solubility of nutrients, and rainfall intensity all affect the time path of nutrient leaching from plant material. Schreiber and McDowell (1985) found that during a single rainfall event the concentration of PO_4, NH_4, and OC in leachate increased rapidly with time, reached a maximum, and then decreased curvilinearly, but NO_3 concentrations were not affected by time. The rapid increase is attributed to the release of nutrient-containing dust particles and easily desorbed nutrients, but as the rainfall continues desorption of nutrients becomes more difficult reducing nutrient concentrations in leachate (Schreiber and McDowell, 1985). An increase in rainfall intensity decreased the time required for the initial increase in nutrient concentrations and the subsequent decrease (Schreiber and McDowell, 1985).

The main purpose of the rainfall simulation component of this project was to determine the proportion of the nitrogen and phosphorus in the cover crops in late fall that would be leached from the crop during rainfall events in the fall and winter. These nutrients would be subject to runoff into surface water particularly if the soil was frozen. The original intention was to conduct rainfall simulations in the field in early winter after the crop had been killed by frost and again in the spring.

On further consideration we concluded that more useful information could be obtained by conducting the simulation studies in the laboratory. Data from field runoff studies would be very difficult to interpret for several reasons. Soil conditions at the time of simulation (moisture content, frozen/unfrozen) would greatly modify both the total and temporal distribution of runoff during the simulation. We have only limited information on the temporal pattern of nutrient leaching from crop residue during a rainfall event. If the nutrients are leached early in the event and the soil is not frozen, most of the nutrients may enter the soil and not appear in the later runoff. If however, the soil surface was frozen, the nutrients would appear in runoff. In addition it would not be possible to separate the nutrient leached from the crop residue from that coming from the soil. Consequently, rainfall simulations were conducted in the School of Engineering using the laboratory rainfall simulator.

4.2 Experimental procedures

The cover crop biomass from a 2.25 m^2 area of each replicate of the high and low nitrogen plots following the wheat crop at the Woodstock site was collected before the crop was killed by frost. The material was frozen at -18•C and retained for rainfall simulation.

Just prior to leaching, the frozen sample was thawed and a portion was allowed to dry at 30•C. The dried and undried material was leached for 45 minutes using two loading rates (2000 kg dry mass ha^{-1} and 4000 kg dry mass ha^{-1}) and two rainfall intensities (2 cm hr^{-1} and 4 cm hr^{-1}). The total leachate was collected using a sampling system which changed collection bottles at 4.5 min intervals giving a total of 10 samples over 45 min. Following the leaching, the plant material was refrozen at -18•C and a second cycle of the same treatments was conducted.

This procedure was repeated to provide replication. There were 96 combinations of simulation situations as follows:

a) 6 cover crop combinations
    3 cover crops (red clover, oilseed radish and annual ryegrass
    2 nitrogen rates applied to the wheat (45 kg ha^{-1} and 180 kg ha^{-1})
b) 2 pre-treatments
    - freezing only
    - freezing (-18•C) and drying (30•C)
c) 2 cycles of freezing or freezing/drying
d) 2 loading rates (2000 kg ha^{-1} and 4000 kg ha^{-1})
e) 2 rainfall intensities (2 cm hr^{-1} and 4 cm hr^{-1})

The simulation equipment used was designed to accommodate four situations (2 pre-treatments x 2 loading rates) at a time. A 1 m^2 sample bed was divided into four compartments of 1 m x 0.25 m. A timed collection system was attached to each of these sections. The rainfall was simulated using the Guelph rainfall simulator.

Sampling of the leachate started at the first sign of fluid flow in the collection system (approximately 4 min after the rainfall commenced). The rainfall and sampling continued for 45 min each with the sample collection continuing for a period after the rainfall was stopped. The samples were immediately frozen at -18•C. All samples were analyzed for dissolved phosphorus, nitrate, and ammonia in the Analytical Services Laboratory in the Dept. of Land Resource Science. This information was used to calculate the weighted mean nutrient concentration (mg L^{-1}), the amount of nutrient leached/kg of plant tissue, and percent of the nutrients leached from the plant material over the rainfall event, (mass of nutrient leached/mass of nutrients in plant sample).

4.3 Results

4.3.1. Temporal pattern of leaching

The volume and nutrient concentrations of leachate collected at each time interval for each leaching condition are presented in Appendix E. There was considerable variability in both volume and nutrient concentrations but there were no discernible differences in temporal patterns for the different cover crops or leaching conditions. The temporal patterns for the concentration of each nutrient for the first and second leaching averaged over all conditions are presented in Figs 4.1 and 4.2. In the first leaching (Fig. 4.1), there was very little change in concentration of NH_4-N during the leaching period. The concentration of P and to a lesser extent $N0_3$-N increased during the first 10-15 minutes of leaching and then gradually declined, but the range of concentrations was not great. The pattern was very similar for the second leaching (Fig. 4.2). The concentration of NH_4-N did not change between the two leachings. The concentration of $N0_3$-N was somewhat but not markedly lower whereas the concentration of P changed only slightly. The lack of marked changes in concentration in the second leaching is surprising. The samples used for the second leaching were the same ones that had been leached in the first leaching and had subsequently been refrozen. The absence of a marked decline in concentration as leaching proceeded even in the second leaching suggests that there is a release of nutrients to the leaching solution over an extended period of leaching. Leaching with 6 cm of water, (the high intensity rate of 4 cm h^{-1} for a total of 90 min) had not removed all the leachable nutrients.

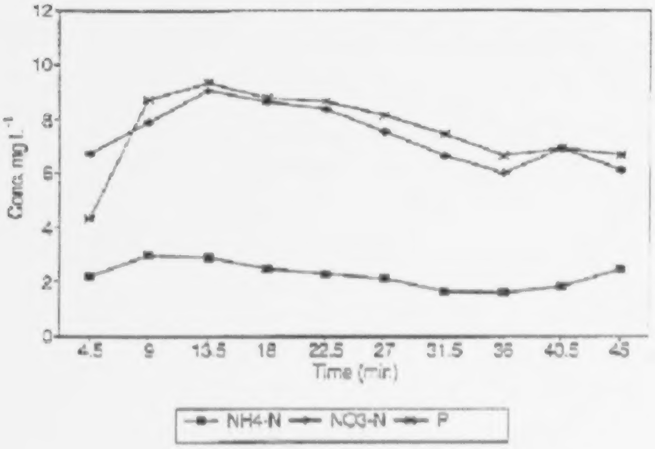


Fig. 4.1 Temporal pattern of nutrient concentration in leachates during first leaching

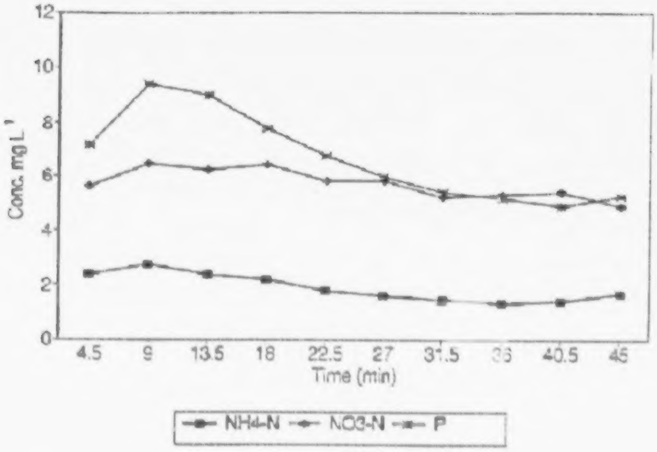


Fig. 4.2 Temporal pattern of nutrient concentration in leachates during second leaching

4.3.2. Influence of cover crop and leaching conditions on mean concentrations of nutrients in leachate

The weighted mean concentrations of nutrients for each leaching combination was calculated as follows:

$$\frac{\overset{\text{sample 10}}{\underset{\text{sample 1}}{\bullet}} \text{ volume of leachate x nutrient concentration}}{\overset{\text{sample 10}}{\underset{\text{sample 1}}{\bullet}} \text{ volume of leachate}}$$

The mean concentrations (averaged over two replicates) for each leaching combination are presented in Appendix F. Also presented in the Appendix F are tables showing the statistical significance of the main effects and interactions of the leaching variables. Because the samples from the field replicates of cover crops and N treatments were bulked, it was not possible to include these parameters in the statistical analysis.

The main effects of loading rate, rainfall intensity freeze/dry treatments and the two leachings are presented in tables 4.1 to 4.3. There were some significant interactions amongst the leaching variables, the most relevant of which will be discussed below. There are, in addition several comparisons between N rate and cover crops which are of interest. These are presented for each nutrient in the following sections.

4.3.2.1 Ammonium-N

As is apparent in Fig. 4.1 and 4.2, the ammonium-N concentration in leachates was considerably lower than either nitrate-N or P. There were no marked differences due to N rate on the main crop or amongst cover crops (Table 4.1). In general, the NH_4-N concentration was higher with the higher loading rate and lower with the higher intensity. Drying the sample (Trt 2) tended to increase the NH_4-N concentration of the subsequent leaching. The mean NH_4-N concentrations in the second leaching of oilseed radish were higher than in the first leaching, whereas the reverse was true with red clover. These effects were observed with both the low and high N treatments although they were statistically significant only with the high N (Table C2). These differences can not be explained, but they do indicate a difference in release of nitrogen from the two cover crops.

Table 4.1. Comparisons of main effects of leaching variables on mean concentration of NH_4-N in leachate.

	Ryegrass		Oilseed Radish		Red Clover	
	Low N	High N	Low N	High N	Low N	High N
				($mg\ L^{-1}$)		
Load 1	0.99	1.51	2.24	1.69	1.35	1.76
Load 2	1.28	2.22	2.42	2.66	2.68	3.40
Intensity 1	1.39	2.45	3.24	2.61	2.16	3.00
Intensity 2	0.87	1.28	1.42	1.74	1.87	2.07
Freeze	1.08	1.91	1.45	1.69	1.62	2.24
Freeze/Dry	1.20	1.82	3.22	2.66	2.41	2.88
Leaching 1	1.21	1.89	2.11	1.81	2.56	2.99
Leaching 2	1.08	1.85	2.56	2.53	1.46	2.08

The leaching x load x intensity interaction was significant for the ryegrass-high N combination. This comparison is presented in Fig. 4.3. With the lower loading rate and intensity, the concentration was lower in the second leaching whereas the reverse was observed at the higher loading rate low intensity treatment. This is probably a reflection of the greater volume of material at the higher loading rate not being fully exposed to the leaching water at the lower intensity during the first leaching. At the higher intensity of leaching, there were no differences due to loading rate or leaching.

The leaching x freeze/dry treatment interaction was significant for the red clover, high N treatment. The NH_4-N concentration in the first leaching was much higher for the dried sample whereas in the second leaching it was somewhat lower (Fig. 4.4). This indicates that the first drying cycle caused release of NH_4-N, which was removed during the first leaching. The second drying treatment did not release as much NH_4-N indicating that the available sources of NH_4-N were being depleted.

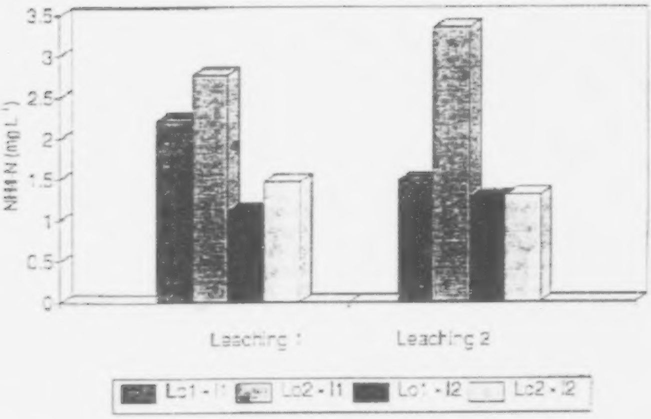


Fig. 4.3 NH_4-N concentration in leachate from ryegrass-high N treatment as influenced by loading rate and intensity during the first and second leaching

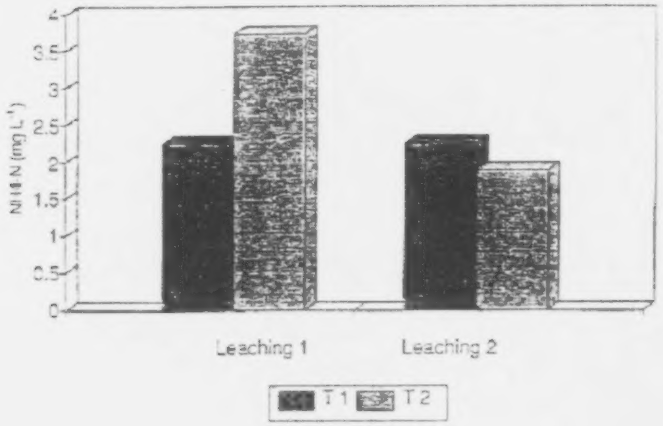


Fig. 4.4 NH_4-N concentration in leachate from red clover-high N treatment as influenced by freeze/dry treatment during first and second leaching

4.3.2.2. Nitrate-N

There were more marked differences in NO_3-N than in NH_4-N concentrations. Leachate from oilseed radish had considerably greater NO_3-N concentrations than either red clover or ryegrass (Table 4.2). The effects of loading rate and intensity of leaching were very similar to those for NH_4-N.

The leaching x freeze/dry treatment x intensity interaction was significant for the rye grass low N sample. This effect was similar to the effect of leaching and treatment on NH_4-N concentrations in the red clover - high N sample (Fig. 4.5). Drying increased the NO_3-N concentration at the low intensity in the first leaching but decreased it in the second. This effect was not evident at the higher leaching intensity.

Table 4.2: Comparisons of main effects of leaching variables on mean concentration of NO_3-N in leachate.

	Ryegrass		Oilseed Radish		Red Clover	
	Low N	High N	Low N	High N	Low N	High N
			(mg L^{-1})			
Load 1	5.09	5.13	8.48	7.91	5.81	5.13
Load 2	5.49	5.80	9.38	10.35	6.12	5.61
Intensity 1	5.66	6.17	10.51	10.37	6.13	5.56
Intensity 2	4.92	4.94	7.35	7.89	5.62	5.14
Freeze	5.27	5.91	9.53	9.78	5.81	4.98
Freeze/Dry	5.31	5.20	8.32	8.48	6.12	5.76
Leaching 1	5.78	5.78	10.64	11.23	6.39	5.71
Leaching 2	4.80	5.34	7.21	7.03	5.54	4.98

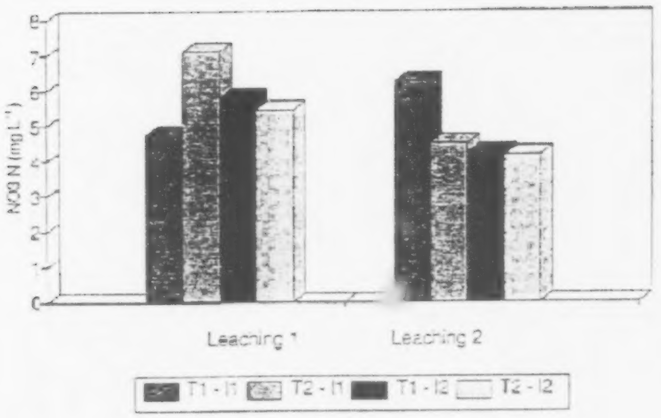


Fig. 4.5 NO_3-N concentration in leachate from ryegrass-low N treatment as influenced by intensity and freeze/dry treatment during first and second leaching

A somewhat similar effect was found with the red clover-low N sample (load x treatment x intensity interaction significant). With the lower loading rate, drying resulted in a greater $N0_3$-N concentration at the higher intensity whereas at the higher loading rate the reverse was true (Fig. 4.6).

4.3.2.3 Phospnorus

There were marked differences in the mean phosphorus concentration amongst the different cover crops. The concentrations were highest for oilseed radish and lowest for red clover (Table 4.3). The concentrations of P were consistently higher for the high N rate on the main crops. This is probably a reflection of the higher P concentration in the cover crop with the higher rate of N application on the main crop. This effect was most noticeable with the ryegrass and the red clover following wheat at Woodstock (Table F2).

The main effects of loading rate, leaching intensity and freeze/dry treatments were very similar to those for $N0_3$-N. As illustrated in Fig. 4.7, the drying treatment in the oilseed-radish low N sample increased the P concentration at the first leaching but decreased it at the second. The P concentration in the second leaching of the sample that had been frozen but not dried was actually greater than in the first leaching, suggesting that repeated freeze/thaw cycles will increase the amount of P leached. The other significant interactions were generally similar to those discussed for $N0_3$-N. A treatment that increased concentration in the first leaching generally decreased it in the second.

The mean concentration of P in one leaching condition of the high N oilseed radish sample (Le-1, Lo-1, T-1, In-2) was much lower than other treatments (Table E16). Both replications of this treatment gave similar results so we must conclude that the value is not an anomally. It can, however, not be explained and did give rise to some of the interactions in both mean concentration of P in the leachate and amount of P leached per unit weight of cover crop biomass.

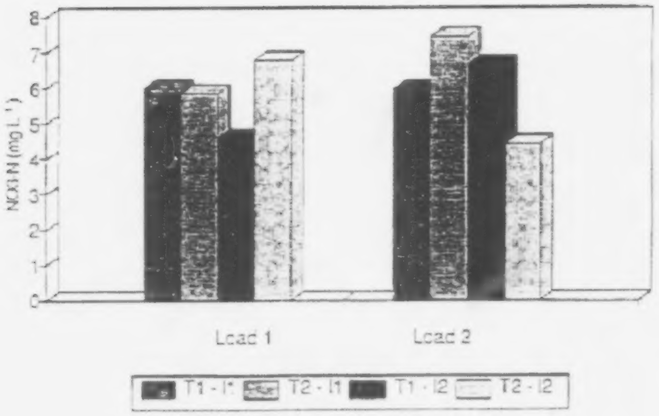


Fig. 4.6 NO_3-N concentration in leachate from red clover-low N treatment as influenced by loading rate and freeze/dry treatment during first and second leaching

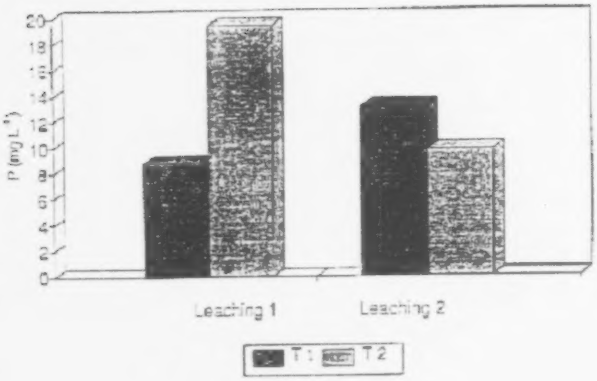


Fig. 4.7 P concentration in leachate from oilseed radish-high N treatment as influenced by freeze/dry treatment at first and second leaching

Table 4.3: Comparisons of main effects of leaching variables on mean concentration of P in leachate.

	Ryegrass		Oilseed Radish		Red Clover	
	Low N	High N	Low N	High N	Low N	High N
				$(mg\ L^{-1})$		
Load 1	4.29	5.61	9.05	10.02	2.07	3.19
Load 2	7.82	10.55	13.18	15.47	3.36	5.15
Intensity 1	7.89	11.01	14.70	16.19	3.75	5.33
Intensity 2	4.22	5.16	7.52	9.30	1.68	2.87
Freeze	6.32	8.60	9.79	10.94	1.97	3.59
Freeze/Dry	5.78	7.57	12.43	14.55	3.46	4.72
Leaching 1	6.14	8.69	12.00	14.10	2.55	4.21
Leaching 2	5.97	7.48	10.23	11.38	2.88	4.06

4.3.3 Influence of cover crop and leaching conditions on amount of nutrient leached per unit mass of cover crop

The amount of nutrient leached per unit mass of cover crop for each cover crop/N combination and each leaching condition is presented in Appendix G. Also presented in Appendix G are tables showing statistical significance of the comparisons within a cover crop/N combination. The main effects of the different leaching conditions are presented in Tables 4.4, 4.5 and 4.6 for NH_4-N, NO_3-N and P respectively.

These values are derived from the mean concentration of nutrient in the leachate and the volume of leachate effects. Thus many of the effects can be readily implied from the mean concentration data. Although loading rate increased the mean concentration, the amount of nutrient removed per unit weight of biomass was generally lower. Leaching intensity generally decreased the concentration of nutrient, but because of the increased volume of leachate, the amount of nutrient leached was relatively independent of intensity. The drying treatment increased both nutrient concentration and amount of nutrient leached per unit of biomass. The amount of nutrient leached per unit of biomass during the second leaching was not consistently different from that during the first leaching.

The significance of interactions also were generally consistent with those for mean concentration. The leaching x intensity interaction for P leached from the oilseed radish low N sample is shown in Fig. 4.8. The amount of P leached per unit of biomass during the first leaching was much greater at the high than at the low intensity, but the reverse was true at the second leaching. Over the two leachings, there was not much difference in the total amount of P removed.

Table 4.4: Amount of NH_4-N leached per unit of biomass.

	Ryegrass		Oilseed Radish		Red Clover	
	Low N	High N	Low N	High N	Low N	High N
				(mg kg^{-1})		
Load 1	84	134	164	143	115	157
Load 2	54	92	104	116	121	151
Intensity 1	59	104	139	114	91	135
Intensity 2	78	123	129	145	145	175
Freeze	63	115	100	110	96	141
Freeze/Dry	74	111	168	148	140	168
Leaching 1	67	109	119	107	155	178
Leaching 2	71	118	150	151	81	129

Table 4.5: Amount of NO_3-N leached per unit of biomass.

	Ryegrass		Oilseed Radish		Red Clover	
	Low N	High N	Low N	High N	Low N	High N
				(mg kg^{-1})		
Load 1	477	509	743	714	544	480
Load 2	253	266	436	455	272	258
Intensity 1	256	288	491	454	283	268
Intensity 2	475	487	687	715	533	484
Freeze	354	426	655	646	394	356
Freeze/Dry	377	349	524	523	421	390
Leaching 1	381	396	694	697	266	390
Leaching 2	349	380	484	472	217	354

Table 4.6: Amount of P leached per unit of biomass.

	Ryegrass		Oilseed Radish		Red Clover	
	Low N	High N	Low N	High N	Low N	High N
				(mg kg^{-1})		
Load 1	364	491	763	824	171	254
Load 2	325	430	567	660	129	217
Intensity 1	315	445	643	700	159	231
Intensity 2	374	477	687	783	140	241
Freeze	351	511	635	652	108	210
Freeze/Dry	338	411	695	831	192	264
Leaching 1	343	499	760	805	155	247
Leaching 2	346	422	570	678	144	225

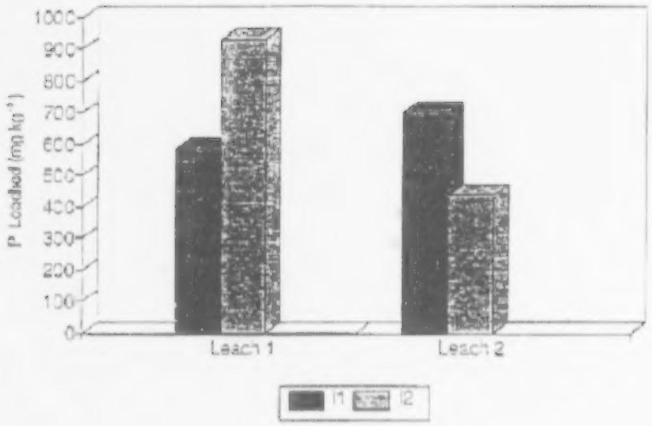


Fig. 4.8 Amount of P leached from oilseed radish-low N treatment as influenced by leaching intensity during first and second leaching

4.3.4 Proportion of nutrient in biomass removed by leaching

The proportion of biomass nitrogen and phosphorus content that was removed by leaching for each cover crop/N rate combination and leaching condition is presented in Appendix H. These data are derived from the values for the amount of nutrient leached per unit of biomass and the nutrient concentration. Because the nutrient concentration was constant for any cover crop/N combination, the statistical significance of leaching condition effects will be identical with those for nutrient leached per unit of biomass. Therefore statistical analyses were not performed on these data. The mean concentration of nitrogen and phosphorus in the cover crop biomass samples from the second sampling from both Ayr and Woodstock are presented in Appendix Table B2. The low and high N cover crop samples from the Woodstock wheat plot were used for the leaching studies.

The main effects of leaching conditions on the proportion of biomass N (NH_4+NO_3) and P leached from each cover crop/N combination are presented in Tables 4.7 and 4.8 respectively.

A considerably lower proportion of N than P was removed by leaching. When both leachings were included, 5 to 10% of the N was removed compared to 20 to 33% of the P. A greater proportion of both N and P was removed from oilseed radish than from ryegrass. The lowest proportion was removed from red clover. The high proportion of P removed from oilseed radish was associated with a considerably greater P concentration in oilseed radish compared to ryegrass or red clover. Thus for a given crop biomass there would be much more P leached from oilseed radish. This is reflected also in the much greater concentration of P in the leachate from this crop (Table 4.3).

Table 4.7: Proportion of N in cover crop biomass removed by leaching.

	Ryegrass		Oilseed Radish		Red Clover	
	Low N	High N	Low N	High N	Low N	High N
			(%)			
Load 1	5.86	4.09	6.31	6.64	4.98	3.05
Load 2	3.15	2.28	3.76	4.42	2.97	1.96
Intensity 1	3.23	2.49	4.39	4.40	2.83	1.92
Intensity 2	5.77	3.88	5.68	6.67	5.13	3.15
Freeze	4.29	3.44	5.25	5.86	3.71	2.38
Freeze/Dry	4.62	2.92	4.81	5.21	4.25	2.67
Leaching 1	4.63	3.21	5.65	6.24	4.48	2.71
Leaching 2	4.30	3.16	4.41	4.83	3.48	2.31
Leaching 1 + 2	8.93	6.37	10.06	11.07	7.96	5.02

Table 4.8: Proportion of P in cover crop biomass removed by leaching.

	Ryegrass		Oilseed Radish		Red Clover	
	Low N	High N	Low N	High N	Low N	High N
			%			
Load 1	15.98	15.45	17.91	18.64	11.07	10.40
Load 2	14.30	13.57	13.34	14.93	8.43	8.90
Intensity 1	13.83	14.01	15.11	15.84	10.36	9.47
Intensity 2	16.46	15.01	16.14	17.72	9.14	9.89
Freeze	15.45	16.09	14.93	14.76	7.02	8.62
Freeze/Dry	14.84	12.93	16.32	18.81	12.47	10.80
Leaching 1	15.07	15.72	17.86	18.22	10.12	10.11
Leaching 2	15.22	13.30	13.40	15.34	9.38	9.21
Leaching 1 + 2	30.29	29.02	31.26	33.56	19.50	19.32

4.3.5 Organic nitrogen, phosphorus and carbon in leachate

The leachate samples from the first leaching of the high N sample from each cover crop (high load, high intensity leaching, drying treatment) were filtered and digested to determine the total N, P and carbon in the leachate. The total N and P concentrations were not greater than the inorganic concentrations presented earlier. This indicates that very little organic N and P was being leached.

Based on the dissolved organic carbon analyses, a total of 33, 72 and 18 kg of dissolved organic C ha^{-1} would be leached from a 4000 kg ha^{-1} crop of ryegrass, oilseed radish and red clover respectively. Although these amounts do not appear large they may contribute significantly to the substrate for denitrifying organisms.

4.4 Discussion and conclusions

As indicated in the introduction to this portion of the project (Sec. 4.0), nutrients leached from cover crop material during the winter and spring are subject to runoff, particularly if the soil surface is frozen. The actual amount or concentrations of nutrients in runoff is dependent on the soil conditions at the time of the rainfall event. The information obtained in this study indicates the potential for contribution to surface water from the different cover crops.

It is of interest to compare the potential concentrations of nutrients in runoff from fields in cover crops with those from bare fields. Spires and Miller (1978) measured NH_4-N, NO_3-N and dissolved P in runoff from over 40 bare farm fields during early spring and late fall rainfall events. Some fields had manure applied and not incorporated. The mean NH_4-N concentration in runoff from fields without manure was 0.26 mg L^{-1} while that from fields with manure was 2.8 mg L^{-1}. The potential concentrations from leaching of cover crops ranges from 1 to 3 mg L^{-1}, approximately the same as that from manured fields. The mean NO_3-N concentrations, which were not different for manured and non manured fields averaged 7.0 mg L^{-1} although the concentration was quite variable. The potential concentration of NO_3-N in leaching from cover crops is quite similar, ranging from 4 to 11 mg L^{-1}. It is difficult to predict whether these two sources of NO_3-N would be additive but it is reasonable to assume that the presence of the cover crop would reduce the amount of NO_3-N leached from the soil. It would appear therefore that the cover crop will have little effect on the NO_3-N concentration in runoff. The dissolved phosphorus concentrations in runoff were 0.16 and 0.70 mg L^{-1} from non manured and manured bare fields respectively. The potential P concentration in runoff from fields with cover crops is in the range of 1 to 3 for red clover, 4 to 11 for rye grass, and 7 to 16 for oilseed radish. Obviously the presence of a cover crop increases the potential dissolved P concentration in runoff to an even greater extent than does the application of manure without incorporation. It must, however, be recognized that the cover crop will reduce erosion through improved soil structure and directly by preventing rain drop splash and reducing rate of runoff. Manure will reduce erosion only through its influence on stability of soil. Thus the total P in runoff would probably be lowered by the presence of the cover crop. Dissolved inorganic P has much greater bioavailability than the sediment-associated P. Sharpley et al (1992) emphasize the importance of dissolved P in runoff in relation to total P. Thus the overall impact of the P in runoff on surface water quality is probably as great from a cover crop as from non-incorporated manure. The potential impact is great for oilseed radish than for ryegrass which, in turn, is greater than for red clover.

The P concentrations observed in this study are comparable to those from other studies reported in the literature. Schrieber (1985) reported P concentrations in leachate from wheat straw of 1 to 5 mg L^{-1} for loading rates ranging from 2200 to 9000 kg ha^{-1}.

5.0 SUMMARY AND CONCLUSIONS

The ideal cover crop, in terms of nutrient conservation, would be one which absorbs N rapidly in the fall resulting in a low residual soil NO_3^- concentration, retains the N (and P) during the winter and spring, then releases the N during the following summer for use by the succeeding crop.

Red clover absorbed the most N in the fall, followed by oilseed radish. Ryegrass absorbed the least N, primarily because of a lower biomass production (Sec. 3.3.1).

All cover crops reduced the NO_3^- content of the soil in the early fall following barley and wheat in comparison with the check plot. There were no consistent differences amongst the cover crops (Sec. 3.3.2).

Nitrate-N concentrations in soil solution at the 75-cm depth were very low throughout the fall at Woodstock. At Ayr they were low for ryegrass and oilseed radish (<10 mg L^{-1}) but were high in October for red clover (54 mg L^{-1} following wheat and 29 following barley) and the no cover crop treatment (43 mg L^{-1}). The values with both red clover and no cover crop decreased considerably by December (Sec. 3.3.3.2), indicating significant leaching of NO_3-N to groundwater. The biomass N content of red clover at Ayr in September was considerably greater than for ryegrass or oilseed radish (Sec. 3.3.1). Red clover apparently fixed considerable N accounting for the high biomass N content but did not reduce the NO_3-N content of the soil as much as ryegrass or oilseed radish thus leaving more to be leached.

Oilseed radish was least effective in retaining N through the winter and spring. The NO_3^- content of the soil in the oilseed radish plots was greater in April and May than with the other cover crops or the check (Sec. 3.3.2). That at least a portion of this NO_3^- was lost by leaching or denitrification is indicated by the fact that the following corn crop contained only slightly more N on the oilseed radish plots than on the check (Sec. 3.3.4). An earlier planted spring crop might have been able to absorb more of the nitrogen released from the oilseed radish. The ease with which N is released from oilseed radish was also shown in the leaching study. In addition to the early release of N, oilseed radish released a much greater amount of P during leaching. This was a result of both a much higher P concentration and a greater proportion of the P being leached (Sec. 4.4.4). Hence oilseed radish has much greater potential for contributing dissolved P in runoff to surface water than either the bare soil or the other two cover crops tested.

Ryegrass appeared to retain N against leaching. However, it was not effective in releasing the N to the succeeding corn crops. The N content and grain yield of the succeeding corn crop was lower following ryegrass than where no cover crop was grown, indicating that ryegrass actually immobilized N (Sec. 3.3.4). Ryegrass released much less P on leaching than did oilseed radish (Sec. 4.3.4).

Red clover was clearly the most effective in retaining the N through the spring and releasing it to the succeeding corn crop (Sec. 3.3.4). Red clover also released the lowest amount of P to leaching so presented the least potential for contributing dissolved P to runoff (Sec. 4.3.4).

In summary, the results from these studies suggest that none of the three cover crops meets all three criteria for an ideal cover crop. In terms of preventing NO_3- leaching to groundwater and P contribution in runoff the data suggest that ryegrass would be the best choice. This must be tempered by the possibility that NO_3- was leached out of the root zone on the ryegrass plot at Ayr prior to the first sampling. Even if this did not occur, the immobilization of N by ryegrass means that additional N must be added to the succeeding corn crop It is not known how much N would be released from the ryegrass during the fall following the second year corn crop. Studies of longer duration are required to answer this question.

All conclusions from this study must be interpreted with considerable caution because they are based on only a one-year study.

6.0 REFERENCES

Alder, V.J. 1988. The transfer of nitrogen from ^{15}N-labelled legume residues to corn and barley using two tillage systems. M.Sc. Thesis, Univ. of Guelph.

Daynard, T.B., M. Tollenaar, T.J. Vyn, T.J. Dekker, and J.F. Muldoon. 1985. Rye-corn sequences for biomass production. Final report for Engineering and Statistical Research Institute, Contract file #23SU-01916-2ER23. Agriculture Canada, Ottawa, Ontario. 81 pp.

Doran, J.W. and M. Scott Smith. 1991. Role of cover crops in nitrogen cycling. pp 85-90. In. Hargrove, W.L. (Ed). Cover Crops for Clean Water. Proceedings of an International Conference, Jackson, Tennessee, April 9-11. 1991. Published by Soil and Water Conservation Society, Ankeny, Iowa.

Meisinger, J.J., W.L. Hargrave, R.K. Mikkelsen, J.R. Williams and V.W. Benson. 1991. Effects of cover crops on groundwater quality. pp. 57-68 In. Hargrove, W.L. (Ed). Cover Crops for Clean Water. Proceedings of an International Conference, Jackson, Tennessee, April 9-11. 1991. Published by Soil and Water Conservation Society, Ankeny, Iowa.

Samson, R.A., C.M. Faulds and D.G. Patriquin. 1991. Effect of cover crops on cycling of nitrogen and phosphorus in a winter wheat - corn sequence. pp 106-107. In. Hargrove, W.L. (Ed). Cover Crops for Clean Water. Proceedings of an International Conference, Jackson, Tennessee, April 9-11. 1991. Published by Soil and Water Conservation Society, Ankeny, Iowa.

Schreiber, J.D., and L.L. McDowell. 1985. Leaching of nitrogen, phosphorus, and organic carbon from wheat straw residues: I. Rainfall Intensity. J. Env. Qual. 14: 251-260.

Schreiber, J.D. 1985. Leaching of nitrogen, phosphorus and organic carbon from wheat straw residues: II Loading Rate. J. Env. qual. 14:256-260.

Sharpley, A.N., S.J. Smith, O.R. Jones, W.A. Berg AND g.a. Coleman. 1992. The transport of bioavailabile phosphorus in agricultural runoff. J. Environ. Qual. 21:30-35.

Sheard, R.W. 1988. The use of red clover in cropping systems. Unpubl. Report Dept. Land Resource Sci., Univ. of Guelph.

Spires, A.C. and M.H. Miller. 1978. Contribution of phosphorus from agricultural land to streams by surface runoff. Report of PLUARG, Task C (Canadian Section) Activity 1: Agricultural Watershed Studies - Proj. 18, Int. Joint Commission, Windsor, Ontario.

Timmons, D.R., R.F. Holt, and J.J. Latterell. 1970. Leaching of crop residues as a source of nutrients in surface runoff water. Water Resourc. Res. 6:1367-1375.

Tukey, H.B. 1971. Leaching of substances from plants. In Ecology of leaf surface microorganisms. Academic Press: London, New York. p 67-80.

Wagger, M.G. and D.B. Mengel. 1988. The role of nonleguminous cover crops in the efficient use of water and nitrogen. Ch. 7 In Cropping Strategies for Efficient Use of Water and Nitrogen. A.S.A. Special Publication No. 51. American Society of Agronomy, Madison, Wisc.

White, E.M. 1973. Water leachable nutrients from frozen or dried prairie vegetation. J. Environ. Qual. 2:104-107.

APPENDIX TABLES

Appendix A

Cover crop biomass

at each of three harvests

(mean of three replicates)

APPENDIX TABLES

APPENDIX TABLES

Appendix A - Cover Crop Biomass at Each of Three Harvests 89

Table A1 - Cover Crop Biomass - Ayr 90

Table A2 - Cover Crop Biomass - Woodstock 91

Appendix B - N and P Concentrations in Cover Crop Biomass at Each of Three Harvests 93

Table B1 - Harvest 1, Nitrogen and Phosphorus Concentration in Cover Crop Biomass 94

Table B2 - Harvest 2, Nitrogen and Phosphorus Concentration in Cover Crop Biomass 95

Table B3 - Harvest 3, Nitrogen and Phosphorus Concentration in Cover Crop Biomass 96

Appendix C - NH_4-N and NO_3-N Concentrations in Soils at Different Dates for Each Cover Crop/N Rate and Soil Depth 97

Table C1 - Ayr Barley 98

Table C2 - Ayr Corn 101

Table C3 - Ayr Wheat 103

Table C4 - Woodstock Barley 104

Table C5 - Woodstock Corn 107

Table C6 - Woodstock Wheat 109

Appendix D - Biomass and N Concentration of Second Year Corn at Two Dates for Each Cover Crop/N Combination 113

Table D1 - Ayr Barley 114

Table D2 - Ayr Corn 115

Table D3 - Woodstock Barley 116

Table D4 - Woodstock Corn 117

Table D5 - Woodstock Wheat 118

Appendix E - Volume of Leachate and Concentration of Ammonium NH_4-N), Nitrate (NO_3-N) and Phosphorus for Each Sampling Interval During the Leaching Period 119

Table E1 - Ryegrass, Low N - Volume (mL) 120

Table E2 - Ryegrass, Low N - NH_4-N (mg L^{-1}) 121

Table E3 - Ryegrass, Low N - NO_3-N (mg L^{-1}) 122

Table E4 - Ryegrass, Low N - P (mg L^{-1}) 123

Table E5 - Ryegrass, High N - Volume (ml) 124

Table E6 - Ryegrass, High N - NH_4-N (mg L^{-1}) 125

Table E7 - Ryegrass, High N - NO_3-N (mg L^{-1}) 126

Table E8 - Ryegrass, High N - P (mg L^{-1}) 127

Table E9 - Oilseed Radish, Low N - Volume (ml) 128

Table E10 - Oilseed Radish, Low N - NH_4-N (mg L^{-1}) 129

Table E11 - Oilseed Radish, Low N - NO_3-N (mg L^{-1}) 130

Table E12 - Oilseed Radish, Low N - P (mg L^{-1}) 131

Table E13 - Oilseed Radish, High N - Volume (ml) 132

Table E14 - Oilseed Radish, High N - NH_4-N (mg L^{-1}) 133

Table E15 - Oilseed Radish, High N - NO_3-N (mg L^{-1}) 134

Table E16 - Oilseed Radish, High N - P (mg L^{-1}) 135

Table E17 - Red Clover, Low N - Volume (mL) 136

Table E18 - Red Clover, Low N - NH_4-N (mg L^{-1}) 137

Table E19 - Red Clover, Low N - NO_3-N (mg L^{-1}) 138

Table E20 - Red Clover, Low N - P (mg L^{-1}) 139

Table E21 - Red Clover, High N - Volume (mL) 140

Table E22 - Red Clover, High N - NH_4-N (mg L^{-1}) 141

Table E23 - Red Clover, Hign N - NO_3-N (mg L^{-1}) 142

Table E24 - Red Clover, High N - P (mg L^{-1}) 143

Appendix F - Weighted Mean Concentration of NH_4-N, NO_3-N, and P in Leachates From Cover Crops and Statistical Significance of Effects 145
Table F1 - Weighted mean concentration of NH_4-N 146
Table F2 - Statistical significance of Weighted Mean Concentration of NH_4-N 147
Table F3 - Weighted mean concentration of NO_3-N 148
Table F4 - Statistical significance of Weighted Mean Concentration of NO_3-N 149
Table F5 - Weighted mean concentration of P 150
Table F6 - Statistical significance of Weighted Mean Concentration of P 151

Appendix G - Amount of Nutrient Leached Per Unit Weight of Cover Crop (MG KG^{-1}) and Statistical Significance of Effects 153
Table G1 - Amount of NH_4-N leached per unit weight of cover crop . 154
Table G2 - Statistical significance of effects - NH_4-N 155
Table G3 - Amount of NO_3-N leached per unit weight of cover crop . 156
Table G4 - Statistical significance of effects - NO_3-N 157
Table G5 - Amount of P leached per unit weight of cover crop . . . 158
Table G6 - Statistical significance of effects - P 159

Appendix H - Proportion of N and P Removed From Cover Crop Biomass by Leaching 161

Table H1 - Proportion of N content of biomass removed by leaching 162
Table H2 - Proportion of P content of biomass removed by leaching 163

Table A1 Cover Crop Biomass - Ayr

Cover Crop	N Rate	Barley[1]			Wheat[2]		
		H1	H2	H3	H1	H2	H3
					kg ha^{-1}		
Ryegrass	0.5	1106	1574	1116	714	1469	1638
	1.0	972	1235	1336	759	1167	1598
	2.0	1237	1582	1399	1149	1285	1685
Oilseed Radish	0.5	2378	3893	3441	1875	2569	2535
	1.0	2127	3144	3621	2220	3081	3442
	2.0	2550	3900	3848	3019	4799	5231
Red Clover	0.5	3632	3389	3395	4386	4387	4434
	1.0	3994	3373	3514	4629	4194	4099
	2.0	3495	3026	3669	5441	4136	4597

[1]/ H1 - Sept. 25 H2 - Oct. 23 H3 - Nov. 13

[2]/ H1 - Sept. 26 H2 - Oct. 23 H3 - Nov. 14

Table A2 Cover Crop Biomass - Woodstock

Cover Crop	N Rate	Barley[1]			Wheat[2]		
		H1	H2	H3	H1	H2	H3
		-------------		kg ha^{-1}			-------------
Ryegrass	0.5	1888	2544	1962	2613	3042	2619
	1.0	1636	2272	1954	2729	3138	2452
	2.0	1654	2455	2250	3449	3162	2529
Oilseed Radish	0.5	1343	2498	2228	1936	2959	3183
	1.0	1410	2096	2049	1586	3730	3018
	2.0	2038	3967	2922	2729	3676	4842
Red Clover	0.5	2659	2518	2554	2914	3000	3325
	1.0	2392	2029	2262	3438	3016	2539
	2.0				3314	2734	2740

[1]/ H1 - Sept. 24 H2 - Oct. 23 H3 - Nov. 13

[2]/ H1 - Sept. 18 H2 - Oct. 22 H3 - Nov. 13

Appendix B

N and P concentrations in cover crop biomass at each of three harvests
(Mean of three replicates)

Table B1 Harvest 1, Nitrogen and Phosphorus Concentration in Cover Crop Biomass

		Ayr				Woodstock			
		Barley		Wheat		Barley		Wheat	
Cover Crop	N Rate	N	P	N	P	N	P	N	P
		---------------------- g kg^{-1} ----------------------							
Ryegrass	0.5	15.6	3.7	14.9	2.7	16.6	3.4	11.5	3.0
	1.0	19.4	3.7	17.9	2.9	12.3	3.4	12.8	2.9
	2.0	17.8	3.6	19.3	3.0	20.5	3.4	15.8	2.9
Oilseed Radish	0.5	20.4	6.2	19.1	5.3	16.8	5.3	15.9	5.2
	1.0	17.8	5.9	19.4	4.9	16.6	5.4	18.2	5.2
	2.0	18.6	5.5	22.6	5.0	18.3	6.6	17.6	5.3
Red Clover	0.5	23.7	3.8	24.4	2.5	30.6	2.9	22.2	2.3
	1.0	16.6	2.8	23.7	2.5	28.2	3.0	20.8	2.4
	2.0	24.2	2.7	24.2	2.5			20.8	2.5

Table B2 Harvest 2, Nitrogen and Phosphorus Concentration in Cover Crop Biomass

		Ayr				Woodstock			
		Barley		Wheat		Barley		Wheat	
Cover Crop	N Rate	N	P	N	P	N	P	N	P
		---------------------- g kg^{-1} ----------------------							
Ryegrass	0.5	18.3	3.4	15.0	3.2	12.7	2.6	9.8	2.3
	1.0	20.1	3.9	15.7	2.4	14.5	3.0	10.5	2.4
	2.0	19.1	3.1	18.6	2.7	16.3	3.4	15.7	3.2
Oilseed Radish	0.5	17.4	5.3	15.3	3.5	15.7	5.1	14.1	4.1
	1.0	15.6	5.1	14.4	4.3	13.3	4.7	13.3	4.2
	2.0	14.6	4.8	21.3	5.0	14.6	4.9	12.8	4.4
Red Clover	0.5	25.2	2.4	23.1	2.1	20.1	2.0	13.4	1.6
	1.0	24.9	2.5	23.1	2.1	24.0	2.4	14.6	1.8
	2.0	25.6	2.5	22.5	2.1			20.9	2.5

Table B3 Harvest 3, Nitrogen and Phosphorus Concentration in Cover Crop Biomass

		Ayr				Woodstock			
		Barley		Wheat		Barley		Wheat	
Cover Crop	N Rate	N	P	N	P	N	P	N	P
		---------------------- g kg^{-1} ----------------------							
Ryegrass	0.5	16.2	2.4	11.3	1.7	13.1	2.3	10.1	1.8
	1.0	14.8	2.5	13.9	1.9	14.3	2.4	12.1	2.2
	2.0	15.2	2.3	13.9	2.0	16.3	2.7	16.6	2.9
Oilseed Radish	0.5	18.5	4.6	14.4	4.1	16.1	4.5	15.8	4.0
	1.0	17.6	4.8	16.2	4.5	13.0	4.5	14.0	3.6
	2.0	16.8	4.7	22.3	4.8	13.2	4.6	13.7	4.1
Red Clover	0.5	24.1	2.1	21.1	2.1	17.9	1.7	14.1	1.5
	1.0	25.0	2.2	25.2	2.1	18.2	1.9	14.1	1.8
	2.0	24.1	2.1	22.7	2.0			19.2	2.6

Appendix C

NH_4-N and NO_3-N Concentrations
in soils at different dates for
each cover crop / N rate and soil depth
(mean of three replicates)

Table C1 Ayr Barley

N Rate	Depth	Ryegrass		Oilseed Radish		Red Clover		Check	
		NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3
	cm	---------------------- mg kg^{-1} ------------------ --							
Sept. 25 1990									
0.5	0 - 15	2.5	1.9	5.0	2.1	4.8	3.1	4.1	3.2
	15 - 30	2.5	1.4	2.4	1.7	4.2	0.9	6.3	3.0
	30 - 45	3.4	1.5	2.6	0.9	4.5	2.2	4.8	1.5
	45 - 60	3.3	1.3	3.1	0.4	2.3	0.9	3.9	5.6
1.0	0 - 15	3.9	1.3	5.9	1.5	5.3	1.5	4.9	3.5
	15 - 30	3.9	1.4	3.2	0.4	3.2	1.4	2.8	3.2
	30 - 45	2.8	1.0	3.5	0.8	4.0	1.3	3.6	2.2
	45 - 60	4.4	1.9	2.6	0.5	3.3	0.9	3.5	2.2
2.0	0 - 15	2.6	1.8	3.8	2.2	3.8	1.3	3.3	3.6
	15 - 30	2.1	0.9	2.6	1.3	3.9	0.7	3.1	1.6
	30 - 45	5.0	2.1	4.0	0.6	2.4	1.4	3.2	1.3
	45 - 60	2.8	1.7	3.3	0.9	3.1	1.8	3.4	1.3
Nov. 16 1990									
0.5	0 - 15	2.9	0.8	2.5	2.9	3.8	3.9	3.3	0.4
	15 - 30	3.1	0.6	3.7	1.9	5.5	2.2	7.1	3.5
	30 - 45	8.6	8.1	3.8	0.8	6.6	3.3	8.0	5.9
	45 - 60	1.4	0.0	2.6	0.0	5.0	1.7	2.6	1.1
1.0	0 - 15	2.6	0.1	4.2	2.0	6.8	3.6	3.0	0.1
	15 - 30	5.9	2.8	4.4	1.4	6.4	2.9	3.5	0.4
	30 - 45	1.6	0.0	4.1	0.1	1.9	0.0	1.1	0.0
	45 - 60	2.9	0.8	3.8	0.0	4.4	1.1	1.6	0.0

Table C1 Ayr Barley

N Rate	Depth	Ryegrass		Oilseed Radish		Red Clover		Check	
		NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3
	cm	----------------------			mg kg^{-1}	------------------			
2.0	0 - 15	10.3	13.2	2.8	1.8	3.5	1.5	3.0	1.1
	15 - 30	5.6	2.0	7.7	2.8	2.3	0.8	1.8	0.0
	30 - 45	1.8	0.0	1.8	0.0	4.3	1.3	1.3	0.0
	45 - 60	11.7	7.9	3.7	0.9	7.0	3.9	6.3	1.8
April 19 1991									
0.5	0 - 15	3.6	0.3	4.0	2.5	9.3	3.1	5.3	0.9
	15 - 30	4.1	0.1	3.5	4.9	4.5	1.6	3.4	1.0
	30 - 45	5.2	0.4	2.2	2.3	6.7	0.8	3.0	0.1
	45 - 60	5.5	0.0	3.1	0.7	2.0	0.3	2.0	0.1
1.0	0 - 15	3.7	0.3	19.7	3.3	5.0	0.9	4.0	0.6
	15 - 30	4.2	0.4	2.5	2.7	4.0	0.7	5.1	0.3
	30 - 45	3.3	0.6	3.1	1.9	4.2	0.2	3.9	0.3
	45 - 60	2.0	0.6	1.4	1.0	4.5	0.1	2.5	0.1
2.0	0 - 15	3.2	0.6	4.2	2.5	5.3	2.3	5.2	1.4
	15 - 30	15.7	0.8	5.0	2.5	4.1	1.2	4.9	1.0
	30 - 45	4.9	0.3	2.8	2.1	3.7	0.8	7.9	1.4
	45 - 60	11.6	0.4	4.4	1.1	4.4	0.9	6.1	0.8
May 6 1991									
0.5	0 - 15	4.9	0.9	3.4	4.1	5.1	4.0	2.7	2.6
	15 - 30	3.9	0.4	3.1	3.6	3.2	1.8	2.2	1.3
	30 - 45	2.8	0.2	1.4	2.4	2.7	0.6	1.8	0.8
	45 - 60	1.4	0.0	1.6	1.5	2.3	0.4	1.5	0.6

Table C1 Ayr Barley

N Rate	Depth	Ryegrass		Oilseed Radish		Red Clover		Check	
		NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3
	cm	---------------------- mg kg^{-1} ------------------ --							
1.0	0 - 15	3.4	1.1	3.8	3.7	6.2	3.0	3.0	2.0
	15 - 30	2.9	0.0	2.8	2.4	2.5	1.7	1.3	1.0
	30 - 45	1.3	0.0	2.3	1.7	2.7	1.1	1.4	0.3
	45 - 60	2.4	0.0	2.2	1.4	1.5	0.5	1.8	0.2
2.0	0 - 15	1.4	2.1	4.3	3.3	2.3	2.8	2.3	1.6
	15 - 30	2.2	0.3	4.3	1.9	1.6	1.3	3.1	0.5
	30 - 45	0.4	0.4	1.8	1.4	0.6	0.3	2.5	0.4
	45 - 60	0.3	0.1	1.8	1.1	0.5	0.2	2.3	0.3
June 24 1991									
0.5	0 - 15	4.0	6.9	6.0	6.2	4.3	18.2	3.8	7.6
	15 - 30	2.9	3.6	2.5	5.9	3.5	13.1	15.0	5.1
	30 - 45	2.1	2.8	2.1	4.2	4.4	6.0	2.0	4.0
1.0	0 - 15	3.5	4.8	2.6	11.1	3.8	22.2	3.8	6.2
	15 - 30	2.6	3.1	3.2	6.4	2.7	9.7	4.1	4.8
	30 - 45	2.0	1.9	2.3	5.4	1.0	6.0	2.8	3.7
2.0	0 - 15	4.8	7.4	2.7	9.2	5.2	17.6	4.2	5.6
	15 - 30	3.5	4.0	2.6	6.2	4.5	12.8	2.2	4.3
	30 - 45	2.4	2.6	2.9	4.2	2.5	6.2	1.8	3.0

Table C2 Ayr Corn

N Rate	Depth	Ryegrass		Winter Rye		Check	
		NH_4	NO_3	NH_4	NO_3	NH_4	NO_3
	cm	mg kg^{-1}					
Oct. 26 1990							
0.5	0 - 15	5.0	2.1	9.0	3.1	5.8	3.1
	15 - 30	5.4	2.0	5.9	2.6	5.8	2.5
	30 - 45	4.6	1.6	4.6	2.3	4.8	2.5
	45 - 60	6.3	1.7	4.4	1.8	9.2	2.5
1.0	0 - 15	5.9	1.6	5.0	1.9	6.2	2.9
	15 - 30	5.3	1.3	4.6	2.1	6.0	2.4
	30 - 45	5.0	1.4	7.6	2.4	4.6	2.2
	45 - 60	4.8	1.3	5.6	2.2	4.1	3.2
2.0	0 - 15	4.6	2.0	6.5	3.5	1.4	4.2
	15 - 30	4.7	2.7	6.5	5.1	5.0	2.4
	30 - 45	5.0	6.4	5.1	5.7	4.5	2.8
	45 - 60	4.6	4.5	4.8	9.3	4.8	4.6
Nov. 20 1990							
0.5	0 - 15	2.7	0.7	1.3	0.8	2.0	0.5
	15 - 30	1.8	0.5	1.9	0.5	1.4	0.7
	30 - 45	0.9	0.0	1.0	0.1	1.4	5.5
	45 - 60	1.0	0.0	2.1	0.3	1.2	0.2
1.0	0 - 15	1.9	0.8	2.1	0.3	2.7	1.1
	15 - 30	1.4	0.5	1.2	0.1	1.8	1.7
	30 - 45	2.2	0.0	1.2	1.8	1.6	1.3
	45 - 60	3.3	0.3	0.8	0.3	1.0	1.8

Table C2 Ayr Corn

N Rate	Depth	Ryegrass		Winter Rye		Check	
		NH_4	NO_3	NH_4	NO_3	NH_4	NO_3
	cm	--------------------	mg kg^{-1}	--------------------			
2.0	0 - 15	2.7	0.5	2.1	0.4	3.5	0.7
	15 - 30	1.4	0.1	1.4	2.4	1.5	0.9
	30 - 45	2.1	0.7	2.0	5.3	1.9	1.3
	45 - 60	1.4	1.6	1.3	4.8	1.8	3.5
April 19 1991							
0.5	0 - 15	6.5	0.4	6.1	0.7	3.4	3.8
	15 - 30	2.7	0.6	3.3	0.4	3.7	1.0
	30 - 45	2.2	0.5	2.3	0.2	3.9	0.7
	45 - 60	1.6	3.0	4.2	0.4	3.4	2.5
1.0	0 - 15	3.2	1.6	4.5	0.7	4.8	1.3
	15 - 30	2.2	1.3	5.8	0.1	2.4	1.1
	30 - 45	0.8	0.4	1.4	0.9	1.6	0.7
	45 - 60	8.4	1.8	5.4	0.3	0.8	0.6
2.0	0 - 15	3.1	1.5	3.7	1.1	1.4	2.2
	15 - 30	2.7	1.2	5.5	0.8	1.7	1.2
	30 - 45	4.0	0.5	3.7	0.6	0.6	1.0
	45 - 60	1.6	0.3	1.4	0.4	1.1	0.8

Table C3 Ayr Wheat

N Rate	Depth	Ryegrass		Oilseed Radish		Red Clover		Check	
		NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3
	cm	mg kg^{-1}							
Sept. 26 1990									
0.5	0 - 15	5.5	2.9	6.6	1.5	5.7	3.8	3.6	3.1
	15 - 30	2.5	2.0	3.4	1.5	6.9	1.9	3.4	2.0
	30 - 45	3.9	0.7	4.2	0.0	3.1	1.2	3.9	1.0
	45 - 60	2.1	1.0	2.3	0.6	3.9	0.2	5.9	1.2
1.0	0 - 15	4.3	2.2	7.0	2.8	4.9	2.3	3.7	7.2
	15 - 30	3.8	1.2	4.6	0.2	3.4	0.3	4.4	3.8
	30 - 45	4.0	1.1	3.4	0.5	3.0	0.9	3.7	1.0
	45 - 60	4.5	0.8	2.9	0.4	4.0	2.0	3.5	1.3
2.0	0 - 15	4.5	2.6	3.4	1.4	5.8	2.4	6.1	4.4
	15 - 30	4.3	2.0	3.8	1.4	4.1	0.8	3.8	2.4
	30 - 45	3.6	1.2	4.5	0.6	4.5	1.1	4.8	1.6
	45 - 60	4.7	1.5	3.7	0.6	2.4	5.9	3.6	1.1
Nov. 19 1990									
0.5	0 - 15	3.0	0.0	2.6	1.2	4.6	2.3	4.0	0.8
	15 - 30	2.9	0.0	3.2	0.0	1.3	0.9	1.6	0.1
	30 - 45	1.6	0.0	1.6	0.0	2.7	0.1	1.6	0.1
	45 - 60	1.6	0.0	0.7	0.0	1.1	0.0	1.5	0.0
1.0	0 - 15	2.6	0.7	2.2	1.7	2.3	1.7	5.7	1.4
	15 - 30	0.8	0.0	2.2	0.6	2.6	0.6	1.2	0.3
	30 - 45	0.9	0.0	0.7	0.1	1.4	0.5	1.2	0.0
	45 - 60	1.1	0.0	1.8	0.0	0.6	0.2	1.3	0.1
2.0	0 - 15	1.9	0.1	4.9	2.1	1.8	2.1	3.2	1.4
	15 - 30	1.9	0.0	1.0	0.5	2.6	0.3	1.3	0.2
	30 - 45	2.2	0.0	3.1	0.3	3.1	0.7	1.7	0.2
	45 - 60	2.1	0.0	2.0	0.1	1.2	0.0	1.0	1.2

Table C4 Woodstock Barley

N Rate	Depth	Ryegrass		Oilseed Radish		Red Clover		Check	
		NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3
	cm	mg kg^{-1}							
Sept. 24 1990									
0.5	0 - 15	4.1	2.1	4.1	2.0	3.3	2.5	3.2	4.4
	15 - 30	2.9	2.1	3.5	2.5	3.3	1.3	4.8	4.6
	30 - 45	4.0	2.1	3.5	0.8	2.3	1.0	3.8	2.7
	45 - 60	3.4	0.8	3.7	0.8	2.9	1.0	4.1	2.3
1.0	0 - 15	5.7	3.2	3.9	4.3	7.2	3.8	4.0	3.1
	15 - 30	5.9	2.7	2.1	1.1	3.5	1.6	4.0	3.5
	30 - 45	4.0	1.2	3.5	1.0	2.1	1.4	2.8	2.5
	45 - 60	2.9	0.7	2.6	1.1	3.8	1.6	4.9	2.8
2.0	0 - 15	3.1	4.1	3.8	3.0			4.8	7.7
	15 - 30	4.4	3.5	2.2	1.2			3.6	5.7
	30 - 45	3.3	1.5	3.9	1.0			5.5	4.7
	45 - 60	3.3	1.5	4.6	1.3			4.0	3.9
Nov. 25 1990									
0.5	0 - 15	1.1	0.0	1.4	0.4	3.1	1.0	2.4	0.0
	15 - 30	3.1	0.2	2.7	0.1	1.9	0.5	2.5	0.2
	30 - 45	1.6	0.0	1.8	0.0	2.8	0.0	1.1	0.0
	45 - 60	2.6	0.0	1.5	0.0	3.0	0.0	1.6	0.0
1.0	0 - 15	1.5	0.0	1.5	1.1	2.4	0.6	1.2	0.0
	15 - 30	1.5	0.0	2.2	0.2	1.6	0.3	2.3	0.0
	30 - 45	1.3	0.0	1.6	0.0	1.4	0.0	2.1	0.2
	45 - 60	1.9	0.0	2.3	0.0	1.7	0.0	2.5	0.0

Table C4 Woodstock Barley

N Rate	Depth	Ryegrass		Oilseed Radish		Red Clover		Check	
		NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3
	cm	----------------------		mg kg^{-1}		-------------------			
2.0	0 - 15	1.4	0.0	2.1	1.7			1.9	0.0
	15 - 30	2.1	0.0	1.7	0.6			1.7	0.0
	30 - 45	1.5	0.0	2.1	0.1			2.7	0.0
	45 - 60	2.1	0.1	2.1	0.0			1.5	0.1
April 25 1991									
0.5	0 - 15	5.2	2.2	3.1	5.8	3.2	4.8	4.1	5.3
	15 - 30	1.3	2.6	2.9	6.3	2.3	4.7	3.0	5.2
	30 - 45	2.2	1.2	6.0	3.9	1.9	3.4	0.8	4.1
	45 - 60	2.0	1.3	2.1	2.9	2.2	2.7	2.1	3.5
1.0	0 - 15	0.8	4.2	3.9	5.4	2.1	3.2	2.8	3.6
	15 - 30	1.3	3.6	1.4	5.1	1.5	3.1	1.5	4.1
	30 - 45	0.2	1.1	1.0	3.7	3.5	2.3	1.7	2.3
	45 - 60	0.8	1.0	0.8	2.9	0.7	2.0	1.3	1.7
2.0	0 - 15	3.3	3.2	1.9	4.7			1.4	4.9
	15 - 30	2.6	2.5	1.7	5.7			0.9	5.7
	30 - 45	3.2	1.0	3.7	4.1			1.4	3.8
	45 - 60	1.6	0.9	3.6	2.6			4.0	2.6
May 10 1991									
0.5	0 - 15	4.6	4.0	1.2	8.5	4.0	8.9	1.3	7.3
	15 - 30	4.5	3.3	2.8	7.6	4.8	5.5	2.0	6.6
	30 - 45	5.2	1.2	2.0	3.8	5.0	2.2	2.5	3.5
	45 - 60	3.0	0.7	2.4	2.2	5.0	1.5	3.8	2.8

Table C4 Woodstock Barley

N Rate	Depth	Ryegrass		Oilseed Radish		Red Clover		Check	
		NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3
	cm	mg kg^{-1}							
1.0	0 - 15	3.7	3.5	4.3	6.7	4.0	5.6	3.6	6.1
	15 - 30	4.4	3.1	3.2	7.0	4.1	3.6	4.1	5.4
	30 - 45	3.2	1.0	3.7	3.2	5.3	1.4	5.8	2.8
	45 - 60	4.6	0.4	2.7	2.0	3.4	1.0	2.0	1.7
2.0	0 - 15	2.9	5.3	3.8	8.8			5.0	6.7
	15 - 30	2.7	4.2	4.5	7.2			4.5	5.8
	30 - 45	3.3	1.5	1.1	3.8			3.9	2.7
	45 - 60	4.6	1.0	2.8	2.5			5.0	1.8
June 28 1991									
0.5	0 - 15	3.6	11.3	2.7	13.2	1.6	27.4	2.1	11.0
	15 - 30	4.8	5.9	3.2	7.9	2.1	12.0	2.5	6.9
	30 - 45	3.7	4.0	2.7	6.0	2.0	10.7	1.9	5.1
1.0	0 - 15	2.6	10.4	2.2	11.9	2.1	34.2	2.6	11.1
	15 - 30	1.7	6.2	2.7	9.5	2.4	13.3	3.1	7.0
	30 - 45	2.5	4.4	2.6	6.8	2.2	10.8	2.6	5.1
2.0	0 - 15	3.1	12.5	3.1	14.9			2.8	14.5
	15 - 30	4.1	6.7	3.8	10.3			2.3	9.8
	30 - 45	4.4	4.2	3.0	6.9			3.5	8.0

Table C5 Woodstock Corn

N Rate	Depth	Winter Rye		Check	
		NH_4	NO_3	NH_4	NO_3
	cm	------------- mg kg^{-1} -------------			
Oct. 26 1990					
0.5	0 - 15	8.0	5.1	8.7	5.2
	15 - 30	7.1	5.6	7.9	6.6
	30 - 45	7.6	4.4	8.9	5.7
	45 - 60	6.5	2.7	7.7	3.7
1.0	0 - 15	5.8	7.5	7.8	8.1
	15 - 30	6.4	11.3	7.9	12.9
	30 - 45	6.9	12.2	6.4	8.9
	45 - 60	5.5	13.7	7.2	8.2
2.0	0 - 15	8.4	14.5	3.9	16.5
	15 - 30	8.9	35.5	11.0	34.8
	30 - 45	6.1	24.8	6.7	26.4
	45 - 60	7.3	15.2	6.3	20.5
Nov. 20 1990					
0.5	0 - 15	1.6	1.3	1.9	1.5
	15 - 30	1.0	2.7	1.1	2.4
	30 - 45	1.1	1.4	1.5	2.0
	45 - 60	1.1	1.0	1.7	1.0
1.0	0 - 15	2.0	3.5	1.3	4.7
	15 - 30	1.4	4.3	2.3	6.9
	30 - 45	2.0	7.8	2.7	6.0
	45 - 60	3.8	8.8	1.0	5.6

Table C5 Woodstock Corn

N Rate	Depth	Winter Rye		Check	
		NH_4	NO_3	NH_4	NO_3
	cm	------------- mg kg^{-1} -------------			
2.0	0 - 15	2.3	3.2	3.5	9.4
	15 - 30	1.9	8.2	1.5	15.4
	30 - 45	2.7	12.3	1.1	12.5
	45 - 60	1.3	10.9	1.3	12.4
April 26 1991					
0.5	0 - 15	4.7	2.6	4.0	2.1
	15 - 30	1.9	4.3	1.9	5.0
	30 - 45	2.7	2.9	3.9	3.5
	45 - 60	3.8	3.1	3.4	3.3
1.0	0 - 15	5.3	4.4	4.4	3.6
	15 - 30	1.7	4.5	1.8	5.1
	30 - 45	3.8	3.5	2.5	4.1
	45 - 60	3.2	3.2	3.2	3.1
2.0	0 - 15	3.1	4.2	0.8	3.3
	15 - 30	3.2	6.5	2.2	5.3
	30 - 45	4.3	4.9	2.4	4.3
	45 - 60	3.8	5.2	2.4	4.8

Table C6 Woodstock Wheat

N Rate	Depth	Ryegrass		Oilseed Radish		Red Clover		Check	
		NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3
	cm	mg kg^{-1}							
Sept. 18 1990									
0.5	0 - 15	1.6	3.9	4.0	3.3	3.6	5.4	1.7	9.5
	15 - 30	1.7	3.3	2.5	3.3	1.8	4.3	1.9	4.9
	30 - 45	1.2	1.3	1.6	2.3	1.2	2.4	1.6	2.0
	45 - 60	3.0	0.9	2.4	1.1	2.7	2.0	1.2	1.6
1.0	0 - 15	2.1	5.1	2.2	3.3	2.6	4.9	1.6	5.5
	15 - 30	2.4	2.0	1.5	2.0	1.5	3.3	1.8	3.3
	30 - 45	2.7	1.7	1.6	1.8	1.8	1.9	1.0	2.8
	45 - 60	1.3	1.4	1.8	1.7	1.4	1.3	1.1	2.2
2.0	0 - 15	1.9	3.8	3.3	3.0	4.0	5.8	3.5	6.8
	15 - 30	1.4	3.0	3.6	3.0	2.3	3.2	1.6	6.4
	30 - 45	1.4	2.7	2.1	1.8	4.3	2.9	1.8	5.2
	45 - 60	1.4	2.0	1.5	2.0	2.0	2.8	0.9	3.7
Nov. 21 1990									
0.5	0 - 15	0.9	0.2	0.8	0.7	4.8	0.8	0.9	0.1
	15 - 30	1.9	0.1	0.7	0.0	1.8	0.7	1.5	0.5
	30 - 45	0.3	0.1	0.4	0.1	0.9	0.3	1.7	0.0
	45 - 60	1.2	0.0	1.0	0.5	1.0	0.8	0.7	0.1
1.0	0 - 15	1.2	0.0	1.9	0.7	4.3	1.2	1.2	0.2
	15 - 30	0.6	0.0	1.8	0.4	0.5	0.6	1.3	0.4
	30 - 45	0.7	0.0	1.2	0.2	1.0	0.2	0.4	0.1
	45 - 60	0.8	0.0	1.1	0.0	1.4	0.4	0.4	0.1

Table C6 Woodstock Wheat

N Rate	Depth	Ryegrass		Oilseed Radish		Red Clover		Check	
		NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3
	cm	mg kg^{-1}							
2.0	0 - 15	1.0	0.0	2.8	1.4	1.0	1.4	1.4	2.3
	15 - 30	1.9	2.3	1.9	1.9	0.9	9.1	1.4	2.4
	30 - 45	1.1	0.4	1.4	1.0	2.0	0.1	1.0	1.4
	45 - 60	1.3	0.2	1.0	1.1	0.9	0.0	0.8	1.3
April 26 1991									
0.5	0 - 15	4.0	4.0	2.7	6.6	4.1	6.0	3.2	5.4
	15 - 30	2.6	3.7	3.4	6.9	2.6	5.6	3.8	5.0
	30 - 45	1.9	2.2	2.4	4.8	3.7	3.0	3.3	2.9
	45 - 60	4.3	1.5	2.5	4.4	5.0	2.8	3.4	2.8
1.0	0 - 15	3.7	5.6	4.9	6.3	5.6	5.8	6.4	4.9
	15 - 30	4.2	4.9	2.7	6.8	4.9	5.4	5.2	4.3
	30 - 45	2.6	3.1	2.2	5.2	3.3	2.9	4.6	2.7
	45 - 60	5.2	2.1	4.7	3.9	3.6	1.9	2.6	2.0
2.0	0 - 15	5.3	4.9	2.7	8.0	6.8	5.1	2.9	5.3
	15 - 30	4.2	5.0	2.0	7.6	2.6	5.3	4.0	4.6
	30 - 45	3.0	1.7	3.5	6.2	4.1	2.5	2.7	2.9
	45 - 60	2.1	1.3	4.0	5.8	2.1	1.9	3.6	2.4
May 8 1991									
0.5	0 - 15	4.2	2.9	2.9	7.9	5.1	7.2	3.3	3.7
	15 - 30	2.8	2.5	1.9	7.4	3.2	5.0	3.0	3.1
	30 - 45	2.2	0.8	2.8	4.1	2.0	1.4	3.5	1.4
	45 - 60	2.0	0.5	2.8	2.6	2.2	1.1	1.7	1.1

Table C6 Woodstock Wheat

N Rate	Depth	Ryegrass		Oilseed Radish		Red Clover		Check	
		NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3
	cm	---------------------- mg kg^{-1}							
1.0	0 - 15	4.4	2.4	4.4	5.2	2.1	5.6	4.9	3.0
	15 - 30	3.5	2.1	3.3	4.7	1.6	3.7	4.0	2.1
	30 - 45	2.9	0.6	2.6	2.5	1.4	1.2	3.6	1.1
	45 - 60	2.5	0.3	3.7	2.2	1.2	0.8	3.0	1.2
2.0	0 - 15	2.7	4.8	2.0	9.0	2.6	6.3	1.7	4.5
	15 - 30	2.1	3.4	1.8	7.5	2.7	2.7	1.8	4.2
	30 - 45	1.5	1.2	2.7	4.5	2.5	1.2	2.3	1.7
	45 - 60	1.7	0.5	1.9	3.3	1.1	2.0	1.5	2.0
June 26 1991									
0.5	0 - 15	2.2	10.5	1.4	16.8	2.3	33.3	1.5	13.7
	15 - 30	2.6	5.7	1.9	10.2	2.2	15.5	2.0	7.5
	30 - 45	2.2	2.8	3.0	7.0	3.1	9.4	1.8	4.9
1.0	0 - 15	2.7	8.8	2.4	15.4	3.0	29.9	3.5	14.3
	15 - 30	3.6	4.9	2.9	8.8	3.4	16.3	3.6	7.9
	30 - 45	1.8	3.9	2.8	5.5	3.5	8.7	3.8	5.1
2.0	0 - 15	2.4	14.8	1.4	20.6	2.7	31.5	2.1	15.1
	15 - 30	2.2	6.2	2.4	11.6	3.6	14.8	2.7	7.9
	30 - 45	2.7	4.1	2.5	7.3	3.5	8.3	3.0	5.5

Appendix D

Biomass and N concentration of second year corn at two dates for each cover crop / N combination (mean of three replicates)

Table D1 Ayr Barley

Cover Crop	N Rate	June 20		July 31	
		DM	N	DM	N
		kg ha^{-1}	g kg^{-1}	kg ha^{-1}	g kg^{-1}
Ryegrass	0.5	1587	22.3	9217	8.5
	1.0	1773	21.2	9355	7.0
	2.0	1804	21.9	9634	9.2
Oilseed Radish	0.5	1750	25.8	9579	11.2
	1.0	1317	27.3	10271	11.3
	2.0	1433	26.8	8892	11.7
Red Clover	0.5	1956	31.8	10010	13.7
	1.0	1927	30.4	12060	13.8
	2.0	1908	29.8	10014	13.0
Check	0.5	1544	26.2	10692	10.2
	1.0	1747	25.2	8884	9.5
	2.0	1184	27.1	9245	9.8

Table D2 Ayr Corn

Cover Crop	N Rate	June 20		July 31	
		DM	N	DM	N
		kg ha^{-1}	g kg^{-1}	kg ha^{-1}	g kg^{-1}
Ryegrass	0.5	1270	24.3	6823	7.2
	1.0	1332	20.5	9190	7.2
	2.0	1209	20.5	9167	7.5
Winter Rye	0.5	1292	21.3	8015	6.3
	1.0	1199	23.5	7939	7.9
	2.0	1121	21.4	8483	9.6
Check	0.5	1458	23.1	9437	8.6
	1.0	1012	24.5	8379	7.5
	2.0	1160	22.5	8056	8.2

Table D3 Woodstock Barley

Cover Crop	N Rate	June 19		Aug. 6	
		DM	N	DM	N
		kg ha^{-1}	g kg^{-1}	kg ha^{-1}	g kg^{-1}
Ryegrass	0.5	633	31.1	8003	7.5
	1.0	600	29.7	8931	7.4
	2.0	551	29.8	8285	6.5
Oilseed Radish	0.5	794	35.7	10921	8.2
	1.0	999	34.6	11778	8.4
	2.0	900	34.9	12777	9.5
Red Clover	0.5	829	39.1	11909	10.9
	1.0	884	37.0	11879	10.7
	2.0				
Check	0.5	773	33.8	10348	8.1
	1.0	907	32.2	10300	7.3
	2.0	873	33.5	11889	9.0

Table D4 Woodstock Corn

Cover Crop	N Rate	June 19		Aug. 2	
		DM	N	DM	N
		kg ha^{-1}	g kg^{-1}	kg ha^{-1}	g kg^{-1}
Winter Rye	0.5	692	30.8	8738	6.9
	1.0	696	32.4	8721	6.5
	2.0	613	29.3	9010	7.2
Check	0.5	690	31.4	8521	7.0
	1.0	717	31.4	9537	6.9
	2.0	732	31.3	9617	7.4

Table D5 Woodstock Wheat

Cover Crop	N Rate	June 19		Aug.7	
		DM	N	DM	N
		kg ha^{-1}	g kg^{-1}	kg ha^{-1}	g kg^{-1}
Ryegrass	0.5	493	32.3	8158	6.8
	1.0	560	30.8	10110	6.5
	2.0	785	32.0	10004	6.7
Oilseed Radish	0.5	938	35.5	12465	10.0
	1.0	856	32.3	11792	9.4
	2.0	902	32.6	12634	10.5
Red Clover	0.5	776	39.0	13356	12.3
	1.0	720	38.3	12495	10.0
	2.0	729	37.1	12335	11.2
Check	0.5	772	36.7	11633	8.4
	1.0	799	32.9	10962	10.2
	2.0	799	32.6	12307	10.0

Appendix E

Volume of leachate and concentration of ammonium (NH_4-N), nitrate (NO_3-N) and phosphorus for each sampling interval during the leaching period.

(Mean of two replicates)

Table E1 Ryegrass, Low N - Volume (mL)

Treatment				Sample									
Lo	In	T	Le	1	2	3	4	5	6	7	8	9	10
1	1	1	1	120	215	262	302	387	320	301	279	150	113
1	1	1	2	270	503	449	493	495	435	485	424	169	35
1	1	2	1	99	290	370	350	445	381	450	340	201	53
1	1	2	2	248	373	463	433	450	421	457	402	109	31
1	2	1	1	455	713	839	631	540	663	745	617	668	191
1	2	1	2	514	758	802	778	793	793	844	635	575	59
1	2	2	1	408	729	850	770	775	789	738	693	549	86
1	2	2	2	619	947	763	750	880	932	681	962	684	248
2	1	1	1	90	139	190	215	256	222	274	240	178	25
2	1	1	2	239	494	550	491	518	432	456	462	117	42
2	1	2	1	41	180	311	328	382	298	333	273	278	188
2	1	2	2	175	370	375	465	408	443	435	473	141	60
2	2	1	1	360	898	755	793	932	818	953	835	263	57
2	2	1	2	548	873	853	610	850	864	855	745	405	74
2	2	2	1	370	745	813	794	798	730	838	725	312	53
2	2	2	2	374	755	647	817	800	683	768	792	488	89

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

T - Treatment, 1= Frozen 2= Dried

Le - Leaching, 1= First Leaching 2= Second Leaching

Table E2 Ryegrass, Low N - NH_4-N (mg L^{-1})

Treatment				Sample									
Lo	In	T	Le	1	2	3	4	5	6	7	8	9	10
1	1	1	1	1.3	1.1	1.6	1.0	0.9	0.6	1.2	0.6	1.4	1.8
1	1	1	2	1.5	1.1	0.8	0.7	0.7	0.6	0.7	0.5	0.6	0.7
1	1	2	1	2.0	3.6	2.8	1.5	2.9	1.6	1.9	1.4	1.3	1.3
1	1	2	2	1.4	1.3	1.4	1.1	1.0	0.8	0.8	0.9	0.7	0.8
1	2	1	1	1.6	0.9	0.7	1.4	0.8	0.6	0.6	0.4	0.7	0.6
1	2	1	2	1.8	0.9	0.8	0.7	0.7	0.8	0.7	0.6	0.8	0.9
1	2	2	1	0.9	0.8	0.9	0.7	0.6	0.9	0.6	0.5	0.5	1.0
1	2	2	2	0.9	0.8	0.7	0.8	0.6	0.4	0.4	0.4	0.3	0.4
2	1	1	1	0.9	2.3	1.8	1.5	1.4	1.4	1.2	1.1	1.2	1.4
2	1	1	2	2.1	3.5	3.1	1.7	2.2	0.9	1.0	1.0	1.0	1.2
2	1	2	1	1.4	1.5	1.9	2.4	1.9	1.6	1.1	1.1	1.2	1.2
2	1	2	2	1.7	1.6	2.3	1.4	1.0	1.1	1.2	0.9	1.2	1.3
2	2	1	1	1.8	1.1	0.8	0.8	0.8	1.0	0.6	0.4	0.5	0.7
2	2	1	2	2.6	1.2	1.1	1.4	0.7	0.7	0.5	0.6	0.8	0.9
2	2	2	1	1.3	1.5	1.0	1.3	1.1	0.9	0.8	0.5	0.7	1.1
2	2	2	2	1.2	1.5	1.4	1.2	1.0	1.1	1.1	1.0	0.9	1.2

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

T - Treatment, 1= Frozen 2= Dried

Le - Leaching, 1= First Leaching 2= Second Leaching

Table E3 Ryegrass Low N - NO_3-N (mg L^{-1})

Treatment				Sample									
Lo	In	T	Le	1	2	3	4	5	6	7	8	9	10
1	1	1	1	4.4	3.8	7.6	5.2	4.5	3.5	9.3	4.5	8.1	4.9
1	1	1	2	4.3	3.7	4.4	5.0	6.1	5.6	4.9	3.8	4.0	5.4
1	1	2	1	4.4	8.4	6.5	4.1	10.1	7.2	5.9	8.2	11.3	5.8
1	1	2	2	3.8	3.6	5.1	4.0	4.0	4.0	3.6	3.7	2.5	3.2
1	2	1	1	8.8	3.2	3.2	10.5	5.5	2.4	5.6	2.9	3.5	2.7
1	2	1	2	5.7	3.7	3.5	3.3	3.8	4.9	3.4	4.5	4.8	4.7
1	2	2	1	4.5	3.5	7.2	9.0	4.5	12.6	5.3	4.1	5.3	5.1
1	2	2	2	3.9	3.3	4.8	6.3	5.0	3.6	3.6	3.4	3.9	3.5
2	1	1	1	5.0	4.8	3.8	4.0	4.3	3.7	4.1	4.0	3.8	4.2
2	1	1	2	4.6	11.4	12.5	7.1	12.4	3.3	4.3	5.7	5.2	3.6
2	1	2	1	4.6	4.5	6.4	9.7	8.1	7.8	5.0	5.8	6.1	6.5
2	1	2	2	4.9	3.6	7.9	4.5	3.3	4.6	7.3	4.8	4.8	3.8
2	2	1	1	6.8	5.5	6.2	6.1	7.4	10.5	9.1	4.1	4.8	3.1
2	2	1	2	5.6	4.4	3.9	7.9	4.1	4.8	3.5	3.7	3.6	3.4
2	2	2	1	3.9	4.8	2.9	6.5	6.4	3.7	5.5	2.4	3.0	3.5
2	2	2	2	3.8	4.0	4.7	3.8	3.3	5.3	5.2	4.1	3.3	3.2

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

T - Treatment, 1= Frozen 2= Dried

Le - Leaching, 1= First Leaching 2= Second Leaching

Table E4 Ryegrass, Low N - P (mg L^{-1})

Treatment				Sample									
Lo	In	T	Le	1	2	3	4	5	6	7	8	9	10
1	1	1	1	1.6	3.8	9.1	4.9	4.1	4.0	9.5	5.0	9.0	3.1
1	1	1	2	8.4	7.3	5.5	4.9	4.9	4.5	3.1	2.9	2.8	4.8
1	1	2	1	2.0	5.9	6.5	3.0	7.5	4.4	6.9	9.5	3.5	4.3
1	1	2	2	5.1	8.0	9.6	6.4	5.6	4.8	3.3	3.8	3.5	3.8
1	2	1	1	2.8	2.8	2.3	6.9	3.9	2.0	4.0	1.5	1.5	2.1
1	2	1	2	5.3	3.3	2.3	2.3	1.8	2.0	1.5	1.8	2.0	2.8
1	2	2	1	4.3	6.1	7.5	7.0	4.6	8.4	4.8	3.5	4.0	3.9
1	2	2	2	2.6	2.3	3.1	1.0	1.0	1.0	0.8	0.8	1.0	0.9
2	1	1	1	3.5	5.5	7.3	7.9	7.0	9.1	8.3	7.4	8.5	8.5
2	1	1	2	13.4	18.6	20.1	14.5	16.9	7.9	8.3	9.4	8.8	9.6
2	1	2	1	2.8	7.3	12.3	16.9	13.0	12.9	9.6	8.5	9.9	10.1
2	1	2	2	5.4	8.4	17.0	6.0	7.1	7.3	9.5	5.4	7.5	6.6
2	2	1	1	6.0	7.3	7.9	8.1	7.3	7.9	5.5	4.1	5.8	5.5
2	2	1	2	11.8	10.0	7.0	12.3	5.8	5.8	3.3	3.5	4.0	5.5
2	2	2	1	2.3	4.0	5.3	4.3	2.6	2.9	2.1	1.6	4.9	3.0
2	2	2	2	7.6	7.5	6.5	5.1	3.3	5.5	2.5	2.4	2.1	3.9

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

T - Treatment, 1= Frozen 2= Dried

Le - Leaching, 1= First Leaching 2= Second Leaching

Table E5 Ryegrass, High N - Volume (mL)

Treatment				Sample									
Lo	In	T	Le	1	2	3	4	5	6	7	8	9	10
1	1	1	1	148	196	258	273	286	351	283	344	217	64
1	1	1	2	283	494	518	483	508	524	485	550	195	69
1	1	2	1	160	332	331	374	390	402	404	368	249	169
1	1	2	2	237	355	359	405	383	436	343	445	293	83
1	2	1	1	453	818	827	824	903	788	857	792	494	58
1	2	1	2	423	898	750	815	808	821	805	786	188	56
1	2	2	1	433	826	745	848	859	775	773	793	255	43
1	2	2	2	375	766	638	765	805	778	865	713	293	45
2	1	1	1	70	263	367	333	403	346	370	432	254	68
2	1	1	2	142	473	510	503	420	390	383	450	347	234
2	1	2	1	49	203	247	276	265	600	320	406	233	90
2	1	2	2	65	284	299	365	348	396	355	399	147	49
2	2	1	1	372	827	818	809	963	815	914	688	345	48
2	2	1	2	580	890	849	848	830	836	853	903	675	188
2	2	2	1	395	677	790	880	841	750	883	783	286	110
2	2	2	2	450	800	816	828	740	923	808	700	115	33

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

T - Treatment, 1= Frozen 2= Dried

Le - Leaching, 1= First Leaching 2= Second Leaching

Table E6 Ryegrass, High N - NH_4-N (mg L^{-1})

Treatment				Sample									
Lo	In	T	Le	1	2	3	4	5	6	7	8	9	10
1	1	1	1	1.7	3.7	2.8	2.1	2.0	1.8	1.4	1.3	1.6	2.0
1	1	1	2	3.6	2.5	2.2	1.2	1.3	1.5	0.9	0.9	0.8	1.3
1	1	2	1	4.9	3.5	2.7	2.1	2.9	2.0	2.3	2.1	1.3	2.2
1	1	2	2	1.3	1.7	1.8	2.2	1.8	1.1	0.8	0.9	0.8	1.4
1	2	1	1	2.2	1.6	1.8	0.7	0.9	0.6	0.3	0.3	0.9	0.7
1	2	1	2	2.1	1.3	1.4	0.9	0.6	0.7	0.7	0.7	0.8	1.1
1	2	2	1	2.0	1.9	1.3	1.0	1.1	1.1	0.9	0.8	0.8	1.0
1	2	2	2	1.7	2.9	1.5	1.5	1.2	1.0	1.7	1.0	0.9	1.2
2	1	1	1	4.6	4.2	4.5	3.6	3.0	2.5	2.0	2.2	2.5	4.9
2	1	1	2	4.2	3.1	4.3	5.7	3.5	4.2	2.2	2.5	1.7	2.0
2	1	2	1	1.4	2.3	2.8	2.5	3.4	2.7	1.8	2.0	1.7	2.2
2	1	2	2	1.9	4.5	4.4	3.9	3.0	3.5	2.9	2.2	2.2	2.5
2	2	1	1	3.8	1.9	2.2	1.0	2.0	0.9	0.8	0.6	1.3	1.6
2	2	1	2	2.0	2.3	2.4	1.9	1.7	1.4	1.5	1.2	1.1	1.7
2	2	2	1	2.0	1.4	1.6	1.3	1.4	1.9	1.1.	1.1	1.3	1.5
2	2	2	2	1.5	1.6	0.9	0.8	0.7	0.7	0.6	0.5	0.7	1.5

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

T - Treatment, 1= Frozen 2= Dried

Le - Leaching, 1= First Leaching 2= Second Leaching

Table E7 Ryegrass, High N - NO_3-N (mg L^{-1})

Treatment				Sample									
Lo	In	T	Le	1	2	3	4	5	6	7	8	9	10
1	1	1	1	6.0	8.3	6.0	4.2	5.4	4.5	3.8	3.5	6.0	4.4
1	1	1	2	7.8	5.8	8.0	3.0	4.4	9.0	4.4	4.6	3.5	4.2
1	1	2	1	13.0	7.4	6.9	6.3	6.9	5.7	7.4	6.6	4.1	7.9
1	1	2	2	4.0	4.3	4.3	8.5	6.6	4.0	3.6	4.4	4.0	7.2
1	2	1	1	12.0	6.1	8.9	5.4	9.1	4.9	3.1	4.3	8.1	3.2
1	2	1	2	5.9	3.8	6.8	3.7	3.4	4.1	5.8	4.3	7.1	4.7
1	2	2	1	5.9	4.6	3.1	3.0	4.2	4.8	4.0	3.1	3.4	2.7
1	2	2	2	3.9	7.3	3.5	3.5	4.5	3.7	6.0	4.0	3.3	3.4
2	1	1	1	6.5	9.2	11.1	8.8	6.3	5.6	3.9	5.1	3.3	10.5
2	1	1	2	9.6	4.8	7.7	16.3	8.3	11.9	4.9	9.5	4.8	4.4
2	1	2	1	3.7	4.5	5.8	4.5	7.3	6.4	3.9	4.6	3.4	3.6
2	1	2	2	5.7	7.2	6.8	6.0	4.7	7.9	5.3	4.6	3.9	4.9
2	2	1	1	9.3	6.9	6.8	2.6	9.3	3.7	4.6	2.4	8.9	4.1
2	2	1	2	3.5	3.8	5.0	4.5	3.5	3.5	5.3	3.4	3.5	3.7
2	2	2	1	5.2	4.4	5.1	4.6	5.4	12.4	5.8	5.1	4.6	5.7
2	2	2	2	4.0	5.2	3.3	3.7	4.6	4.1	4.3	3.3	5.7	5.9

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

T - Treatment, 1= Frozen 2= Dried

Le - Leaching, 1= First Leaching 2= Second Leaching

Table E8 Ryegrass, High N - P (mg L^{-1})

Treatment				Sample									
Lo	In	T	Le	1	2	3	4	5	6	7	8	9	10
1	1	1	1	7.3	9.5	10.8	9.4	9.1	8.5	7.4	7.9	8.4	9.0
1	1	1	2	12.6	8.6	8.0	3.5	3.6	4.6	3.1	2.5	3.4	3.3
1	1	2	1	9.6	10.9	9.3	8.6	13.4	8.4	9.8	7.4	6.0	8.6
1	1	2	2	3.3	5.3	6.5	7.3	6.6	4.6	3.8	4.3	3.8	6.3
1	2	1	1	7.9	8.5	7.9	4.9	7.3	4.0	3.1	2.9	5.4	4.1
1	2	1	2	7.0	4.3	5.5	2.3	2.0	2.0	2.0	3.3	3.3	4.0
1	2	2	1	4.8	6.5	3.9	2.4	3.5	4.5	1.1	1.6	1.6	2.5
1	2	2	2	8.8	6.0	4.4	3.6	3.8	2.3	2.0	1.6	2.3	2.3
2	1	1	1	5.8	17.4	16.9	15.1	14.0	12.1	10.5	11.3	13.0	19.8
2	1	1	2	12.5	15.8	23.5	25.0	21.9	13.6	12.6	15.0	10.9	12.4
2	1	2	1	2.8	8.1	15.4	12.1	16.5	13.5	8.8	12.0	7.9	9.1
2	1	2	2	8.0	19.0	22.3	21.0	15.8	16.3	15.4	11.1	10.9	13.3
2	2	1	1	4.3	12.0	11.3	7.3	9.1	7.0	7.1	4.8	9.4	9.0
2	2	1	2	5.5	8.0	8.5	7.3	5.8	4.5	6.3	3.5	3.5	5.5
2	2	2	1	6.9	8.0	9.8	8.3	9.0	10.8	8.3	7.4	8.6	7.9
2	2	2	2	3.5	5.6	2.5	2.0	1.8	1.5	1.5	1.5	2.6	2.3

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

T - Treatment, 1= Frozen 2= Dried

Le - Leaching, 1= First Leaching 2= Second Leaching

Table E9 Oilseed Radish, Low N - Volume (ml)

Treatment				Sample									
Lo	In	T	Le	1	2	3	4	5	6	7	8	9	10
1	1	1	1	119	365	358	421	414	365	455	360	263	41
1	1	1	2	364	478	695	718	651	657	669	668	85	29
1	1	2	1	83	153	221	243	268	270	354	338	355	258
1	1	2	2	443	303	324	363	348	353	230	191	235	70
1	2	1	1	395	719	605	736	716	965	910	862	166	34
1	2	1	2	605	873	828	823	790	875	888	715	236	38
1	2	2	1	370	810	784	775	809	826	817	773	251	39
1	2	2	2	724	712	720	663	792	648	678	383	642	60
2	1	1	1	122	275	419	473	514	369	481	442	190	45
2	1	1	2	206	438	573	588	620	561	649	609	193	44
2	1	2	1	93	348	405	390	420	450	568	415	334	101
2	1	2	2	415	307	352	344	373	340	232	183	117	45
2	2	1	1	307	697	753	598	720	712	1005	683	567	47
2	2	1	2	560	730	788	713	888	700	928	640	647	70
2	2	2	1	414	690	918	660	639	910	848	778	518	123
2	2	2	2	755	505	758	758	843	739	800	819	528	70

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

T - Treatment, 1= Frozen 2= Dried

Le - Leaching, 1= First Leaching 2= Second Leaching

Table E10 Oilseed Radish, Low N - NH_4-N (mg L^{-1})

Treatment				Sample									
Lo	In	T	Le	1	2	3	4	5	6	7	8	9	10
1	1	1	1	1.2	1.5	2.3	2.0	1.9	1.7	1.4	1.2	1.4	1.9
1	1	1	2	2.3	2.0	1.6	1.3	1.5	1.3	1.0	1.0	1.0	1.3
1	1	2	1	3.7	8.2	8.4	5.9	5.5	3.8	4.6	4.5	5.0	5.4
1	1	2	2	2.9	6.4	5.9	5.2	4.3	3.1	4.8	3.2	5.3	3.9
1	2	1	1	1.9	1.0	0.8	0.8	0.5	0.4	0.5	0.5	0.5	1.2
1	2	1	2	2.1	1.4	1.1	1.1	0.9	0.9	0.9	0.8	0.8	1.2
1	2	2	1	3.9	2.6	1.7	1.3	1.2	1.2	1.0	0.9	1.3	1.3
1	2	2	2	2.8	2.7	1.6	1.5	1.2	1.0	0.7	0.9	0.6	1.2
2	1	1	1	1.6	2.1	2.7	3.7	2.0	1.6	1.5	2.0	1.4	1.9
2	1	1	2	2.6	4.0	2.4	2.0	1.8	1.9	1.8	2.2	1.9	3.2
2	1	2	1	1.6	2.7	2.7	2.4	2.4	1.9	2.2	2.4	2.1	2.2
2	1	2	2	6.6	8.2	7.4	5.6	5.7	4.8	6.0	4.7	4.2	5.0
2	2	1	1	0.8	1.9	1.2	1.3	1.6	0.9	0.7	0.5	0.7	1.2
2	2	1	2	2.0	2.5	2.3	1.2	1.0	0.9	0.8	0.7	0.8	1.1
2	2	2	1	1.5	3.2	1.3	1.9	1.8	2.1	1.7	1.3	1.8	3.3
2	2	2	2	2.3	3.2	3.2	2.4	2.1	2.1	1.7	2.0	1.2	3.3

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

T - Treatment, 1= Frozen 2= Dried

Le - Leaching, 1= First Leaching 2= Second Leaching

Table E11 Oilseed Radish, Low N - NO_3-N (mg L^{-1})

Treatment				Sample									
Lo	In	T	Le	1	2	3	4	5	6	7	8	9	10
1	1	1	1	10.7	10.6	29.1	18.1	11.1	11.6	10.0	6.5	10.5	9.3
1	1	1	2	6.3	7.6	8.1	5.8	14.1	11.7	6.8	9.0	5.1	4.9
1	1	2	1	6.2	12.5	18.4	9.7	7.8	5.9	8.1	7.9	8.8	11.3
1	1	2	2	5.8	14.5	10.1	9.3	7.8	5.6	10.2	5.4	13.6	6.5
1	2	1	1	20.2	9.3	7.6	7.1	5.9	6.4	5.8	7.0	4.9	8.9
1	2	1	2	10.1	5.7	7.0	7.3	4.2	4.5	4.4	4.9	3.9	5.1
1	2	2	1	21.5	17.3	9.8	7.3	7.4	8.3	5.6	4.8	11.9	3.8
1	2	2	2	5.1	5.9	4.4	4.9	3.7	5.0	3.9	5.6	3.3	4.5
2	1	1	1	5.3	10.2	17.8	25.0	12.8	9.8	11.5	17.6	7.9	7.7
2	1	1	2	7.0	14.7	8.3	7.4	7.7	9.9	9.9	15.1	9.5	10.9
2	1	2	1	6.9	8.8	11.1	10.8	11.8	7.7	11.0	16.8	10.9	6.7
2	1	2	2	14.1	14.4	9.0	8.5	8.7	7.2	7.8	5.9	6.2	6.3
2	2	1	1	6.5	14.4	10.1	12.5	17.7	9.7	7.0	5.0	7.9	4.9
2	2	1	2	6.0	9.5	12.4	5.3	5.9	5.7	3.7	4.2	6.2	4.5
2	2	2	1	6.8	18.7	6.4	9.9	8.6	12.5	6.5	4.6	9.8	13.3
2	2	2	2	4.1	5.3	5.5	5.0	4.1	5.3	4.2	4.5	4.1	5.3

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

T - Treatment, 1= Frozen 2= Dried

Le - Leaching, 1= First Leaching 2= Second Leaching

Table E12 Oilseed Radish, Low N - P (mg L^{-1})

Treatment				Sample									
Lo	In	T	Le	1	2	3	4	5	6	7	8	9	10
1	1	1	1	4.9	10.6	9.9	11.4	11.3	9.4	8.9	8.4	9.4	8.6
1	1	1	2	16.0	14.0	10.8	9.8	7.8	6.0	4.5	8.5	6.0	5.5
1	1	2	1	4.3	10.9	13.5	14.9	13.9	13.0	13.5	13.4	12.0	13.0
1	1	2	2	11.5	17.1	14.6	14.3	12.6	14.5	13.1	16.3	12.5	11.8
1	2	1	1	10.0	9.3	7.4	7.1	7.3	6.0	6.4	6.4	4.9	6.6
1	2	1	2	5.3	7.8	5.8	6.5	4.0	3.5	2.5	2.8	2.8	4.3
1	2	2	1	12.3	18.5	15.3	11.9	8.5	11.8	7.9	7.0	5.9	6.8
1	2	2	2	4.3	7.3	3.9	1.5	1.4	1.5	1.0	3.1	2.8	0.3
2	1	1	1	5.0	10.8	15.8	17.4	15.6	12.9	13.0	16.1	12.3	9.6
2	1	1	2	10.9	24.8	22.1	20.4	17.3	21.8	16.5	16.0	14.0	17.4
2	1	2	1	3.8	18.5	11.6	24.1	22.3	18.0	18.8	21.3	20.8	19.4
2	1	2	2	17.9	22.6	21.8	19.8	20.4	16.8	19.8	18.1	11.5	9.0
2	2	1	1	6.1	13.8	11.6	11.1	9.1	7.9	6.6	4.9	5.8	5.3
2	2	1	2	8.3	11.0	8.8	2.5	7.0	4.5	4.0	3.5	4.0	5.3
2	2	2	1	7.5	16.7	16.4	16.0	13.3	14.6	12.0	8.8	11.4	7.3
2	2	2	2	2.9	9.4	11.9	4.4	6.8	5.4	5.4	3.0	3.6	3.0

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

T - Treatment, 1= Frozen 2= Dried

Le - Leaching, 1= First Leaching 2= Second Leaching

Table E13 Oilseed Radish, High N - Volume (ml)

Treatment				Sample									
Lo	In	T	Le	1	2	3	4	5	6	7	8	9	10
1	1	1	1	125	300	375	314	324	298	468	403	361	233
1	1	1	2	341	430	610	634	541	607	661	415	265	34
1	1	2	1	110	284	308	367	320	409	344	438	203	278
1	1	2	2	393	257	318	346	305	317	168	220	310	215
1	2	1	1	524	794	871	830	945	785	959	883	373	50
1	2	1	2	318	760	552	572	780	963	727	947	399	51
1	2	2	1	275	850	714	737	799	815	852	745	325	44
1	2	2	2	689	700	708	623	680	635	578	260	510	525
2	1	1	1	103	279	365	485	460	475	483	473	198	50
2	1	1	2	110	328	435	558	372	478	455	479	275	97
2	1	2	1	52	320	335	273	390	423	393	375	275	133
2	1	2	2	485	303	390	394	286	360	244	194	225	49
2	2	1	1	331	738	685	716	855	787	914	784	502	75
2	2	1	2	363	691	692	801	799	715	886	585	608	102
2	2	2	1	337	650	791	825	807	893	763	903	227	69
2	2	2	2	723	798	750	803	781	738	648	525	215	110

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

T - Treatment, 1= Frozen 2= Dried

Le - Leaching, 1= First Leaching 2= Second Leaching

Table E14 Oilseed Radish, High N - NH_4-N (mg L^{-1})

Treatment				Sample									
Lo	In	T	Le	1	2	3	4	5	6	7	8	9	10
1	1	1	1	1.1	1.5	1.8	1.4	1.4	1.5	1.3	1.1	1.5	1.2
1	1	1	2	2.6	2.1	1.9	1.3	1.8	1.2	1.1	1.0	0.9	1.4
1	1	2	1	2.9	2.4	2.2	1.9	2.3	2.1	1.7	1.9	2.6	2.6
1	1	2	2	2.4	3.5	3.6	5.1	3.7	3.2	3.0	2.9	2.4	2.6
1	2	1	1	1.1	0.8	1.5	1.3	0.7	0.6	0.7	0.6	0.6	1.4
1	2	1	2	2.6	2.5	1.7	1.5	1.1	1.5	0.8	0.7	0.9	1.6
1	2	2	1	1.7	1.6	1.4	1.4	1.0	0.7	0.8	0.9	0.6	1.2
1	2	2	2	1.9	3.1	2.0	2.0	2.1	1.4	1.1	1.1	1.0	1.1
2	1	1	1	1.4	2.1	2.2	4.1	2.5	2.9	2.3	1.5	1.5	3.3
2	1	1	2	4.3	5.5	3.1	3.5	2.4	2.4	2.3	1.8	1.7	2.3
2	1	2	1	1.3	3.7	2.7	2.8	4.9	2.8	1.9	1.6	1.7	2.7
2	1	2	2	2.6	4.4	5.5	5.2	4.5	4.3	3.3	3.9	5.7	4.1
2	2	1	1	0.7	1.1	1.7	1.8	1.8	1.4	0.8	0.8	1.0	1.8
2	2	1	2	1.8	2.5	2.6	2.1	1.5	1.2	1.2	1.1	1.1	2.3
2	2	2	1	2.9	3.0	3.3	3.2	2.7	2.2	2.1	1.6	1.5	2.6
2	2	2	2	2.6	3.0	2.9	5.1	4.0	2.9	1.9	2.5	3.1	3.3

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

T - Treatment, 1= Frozen 2= Dried

Le - Leaching, 1= First Leaching 2= Second Leaching

Table E15 Oilseed Radish, High N - NO_3 - N (mg L^{-1})

Treatment				Sample									
Lo	In	T	Le	1	2	3	4	5	6	7	8	9	10
1	1	1	1	5.8	9.9	14.4	8.6	10.9	11.7	9.1	8.5	16.7	8.8
1	1	1	2	10.2	6.9	6.0	4.8	11.7	7.9	7.4	5.7	5.4	4.6
1	1	2	1	4.9	8.8	8.9	7.7	12.5	11.7	8.7	10.7	14.7	12.0
1	1	2	2	4.8	4.7	5.0	7.8	6.6	5.3	4.9	4.5	3.2	4.0
1	2	1	1	7.2	5.5	16.8	11.2	4.8	4.4	4.9	4.5	4.0	7.8
1	2	1	2	7.7	9.6	5.9	8.1	4.7	13.4	5.9	4.9	5.1	5.7
1	2	2	1	12.3	9.0	10.0	12.4	8.5	5.4	7.0	11.7	5.7	9.2
1	2	2	2	5.1	6.4	4.9	6.3	8.2	4.8	4.4	4.2	3.8	4.7
2	1	1	1	7.3	15.5	14.8	34.7	16.9	19.8	16.0	8.9	8.8	17.3
2	1	1	2	9.9	20.3	11.1	13.7	7.6	8.9	9.0	6.4	6.3	9.4
2	1	2	1	5.0	14.1	12.4	15.0	33.3	15.8	11.1	8.7	8.8	10.2
2	1	2	2	4.2	5.5	7.5	7.5	6.8	6.4	4.6	4.9	7.2	4.6
2	2	1	1	6.0	7.1	12.4	16.2	16.4	12.7	5.4	5.8	7.3	6.2
2	2	1	2	6.2	6.9	9.0	9.1	6.3	5.4	5.6	6.5	7.4	9.1
2	2	2	1	9.1	9.6	12.5	12.9	13.4	7.4	9.3	6.7	5.0	6.3
2	2	2	2	5.5	4.8	5.3	10.1	8.6	7.5	4.7	7.2	6.3	3.7

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

T - Treatment, 1= Frozen 2= Dried

Le - Leaching, 1= First Leaching 2= Second Leaching

Table E16 Oilseed Radish, High N - P (mg L^{-1})

Treatment				Sample									
Lo	In	T	Le	1	2	3	4	5	6	7	8	9	10
1	1	1	1	3.8	11.5	14.8	13.0	13.1	13.6	12.4	10.9	13.5	10.4
1	1	1	2	16.5	15.8	14.0	9.5	11.8	8.0	10.0	8.3	5.3	9.3
1	1	2	1	5.5	14.8	17.3	17.4	16.5	18.4	17.4	16.0	20.1	11.1
1	1	2	2	10.6	11.5	11.8	14.5	12.3	9.9	8.5	12.5	5.3	4.5
1	2	1	1	0.5	1.3	1.6	1.5	1.3	0.5	1.5	0.6	1.3	0.6
1	2	1	2	10.5	13.3	10.8	7.8	6.3	11.5	6.5	3.8	5.8	6.5
1	2	2	1	7.1	14.8	15.8	17.0	13.5	10.1	12.8	12.1	10.1	7.5
1	2	2	2	3.0	7.6	7.9	6.1	4.9	4.5	3.9	4.3	5.0	5.3
2	1	1	1	4.4	13.9	16.6	18.0	17.8	16.5	16.5	15.3	14.0	13.6
2	1	1	2	18.3	28.0	24.6	27.3	19.0	18.3	19.5	16.1	13.3	13.8
2	1	2	1	3.9	26.6	27.4	28.6	33.4	28.4	26.3	24.4	23.1	21.9
2	1	2	2	9.4	13.6	17.1	14.6	14.1	12.4	12.8	5.4	13.5	8.8
2	2	1	1	3.9	7.5	9.1	3.9	8.1	8.8	5.4	3.8	4.4	4.4
2	2	1	2	8.5	17.5	16.3	14.3	13.3	8.5	9.0	8.8	7.5	10.3
2	2	2	1	15.5	24.9	28.3	23.3	22.8	18.1	20.5	14.5	14.3	16.4
2	2	2	2	6.8	9.0	7.1	10.1	7.4	6.8	6.0	6.8	6.9	8.0

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

T - Treatment, 1= Frozen 2= Dried

Le - Leaching, 1= First Leaching 2= Second Leaching

Table E17 Red Clover, Low N - Volume (mL)

Treatment				Sample									
Lo	In	T	Le	1	2	3	4	5	6	7	8	9	10
1	1	1	1	46	261	252	248	388	335	408	398	318	63
1	1	1	2	301	333	389	370	417	303	407	325	170	43
1	1	2	1	204	383	403	450	446	485	465	475	160	63
1	1	2	2	106	318	388	328	377	408	380	297	261	90
1	2	1	1	330	871	976	813	785	785	970	790	575	50
1	2	1	2	357	667	553	995	813	903	893	853	468	63
1	2	2	1	408	663	698	703	755	708	583	730	513	55
1	2	2	2	336	598	710	930	1028	818	1020	935	206	60
2	1	1	1	71	251	673	402	401	473	376	443	179	40
2	1	1	2	169	495	408	400	365	353	394	319	168	41
2	1	2	1	28	173	362	323	379	396	455	455	388	150
2	1	2	2	87	323	385	382	420	327	398	372	210	90
2	2	1	1	253	518	688	933	733	836	820	788	523	110
2	2	1	2	505	833	745	870	737	783	700	801	305	43
2	2	2	1	185	600	578	638	668	620	633	665	423	213
2	2	2	2	351	765	808	709	883	695	888	725	225	35

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

T - Treatment, 1= Frozen 2= Dried

Le - Leaching, 1= First Leaching 2= Second Leaching

Table E18 Red Clover, Low N - NH_4-N (mg L^{-1})

Treatment				Sample									
Lo	In	T	Le	1	2	3	4	5	6	7	8	9	10
1	1	1	1	1.9	2.3	3.7	3.4	3.7	1.5	0.9	0.9	0.6	0.7
1	1	1	2	2.6	2.0	1.7	1.2	1.0	0.9	0.9	1.0	0.9	0.9
1	1	2	1	2.6	3.0	2.9	1.5	1.2	1.1	1.3	0.8	0.8	1.3
1	1	2	2	1.8	2.7	2.2	2.7	1.5	1.5	1.1	1.0	1.4	1.4
1	2	1	1	1.7	1.4	1.5	1.0	1.3	0.7	0.6	0.7	0.8	0.8
1	2	1	2	0.7	1.2	1.4	0.7	0.6	0.5	0.4	0.4	0.4	0.6
1	2	2	1	1.8	4.8	1.8	1.6	1.4	1.0	1.5	1.0	1.5	1.3
1	2	2	2	1.1	0.9	0.7	0.6	0.7	0.4	0.7	0.5	0.6	0.6
2	1	1	1	1.1	4.1	4.0	4.9	2.3	1.8	1.9	2.4	2.0	1.8
2	1	1	2	3.3	3.7	2.8	2.7	2.2	1.7	1.6	1.8	1.7	1.6
2	1	2	1	2.2	3.4	4.4	2.5	2.5	3.0	2.3	1.6	1.7	2.0
2	1	2	2	2.9	4.2	3.2	3.1	2.3	2.1	2.1	1.8	1.9	1.3
2	2	1	1	1.3	3.1	4.6	2.3	1.0	0.9	0.9	0.7	1.0	1.0
2	2	1	2	2.5	2.1	1.4	1.4	1.2	1.1	1.1	0.8	1.0	1.2
2	2	2	1	5.7	8.9	9.2	7.7	5.7	6.0	5.9	4.8	6.4	7.4
2	2	2	2	1.3	1.3	1.2	1.5	0.8	0.6	0.5	0.6	0.6	0.7

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

T - Treatment, 1= Frozen 2= Dried

Le - Leaching, 1= First Leaching 2= Second Leaching

Table E19 Red Clover, Low N - NO_3-N (mg L^{-1})

Treatment				Sample									
Lo	In	T	Le	1	2	3	4	5	6	7	8	9	10
1	1	1	1	5.7	5.4	9.0	9.1	14.0	8.2	4.7	5.2	5.2	3.8
1	1	1	2	4.3	4.1	4.9	3.8	3.7	5.7	4.4	7.8	5.7	3.6
1	1	2	1	5.5	8.1	10.2	4.7	4.1	4.4	6.6	3.7	3.4	3.9
1	1	2	2	6.9	7.9	5.8	10.6	4.4	5.5	3.4	3.7	8.5	5.9
1	2	1	1	5.7	3.1	5.2	3.5	9.1	2.9	2.8	3.5	5.0	2.8
1	2	1	2	4.1	4.1	10.4	5.0	5.7	3.6	3.7	3.6	3.6	3.7
1	2	2	1	4.8	14.8	5.2	6.0	5.7	4.2	12.1	4.0	13.7	5.4
1	2	2	2	5.5	3.6	4.0	4.3	8.9	3.6	5.3	7.9	7.3	5.8
2	1	1	1	2.1	6.8	7.9	13.4	5.0	4.7	5.5	8.9	5.8	3.9
2	1	1	2	5.7	5.2	4.9	6.1	5.0	4.6	4.7	6.9	6.5	4.0
2	1	2	1	5.5	7.6	8.9	5.6	6.4	9.3	7.7	5.0	6.8	6.2
2	1	2	2	4.8	10.6	7.4	8.5	5.4	5.9	9.1	8.2	8.8	4.4
2	2	1	1	4.3	8.9	17.3	13.4	4.2	3.9	6.0	3.6	8.2	3.7
2	2	1	2	4.9	5.9	4.6	6.4	5.9	5.5	7.3	4.5	5.1	5.0
2	2	2	1	4.6	4.4	5.5	4.2	3.3	4.6	6.5	3.6	5.0	4.2
2	2	2	2	3.9	3.7	4.0	8.1	3.6	2.6	3.2	4.7	3.5	3.2

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

T - Treatment, 1= Frozen 2= Dried

Le - Leaching, 1= First Leaching 2= Second Leaching

Table E20 Red Clover, Low N - P (mg L^{-1})

Treatment				Sample									
Lo	In	T	Le	1	2	3	4	5	6	7	8	9	10
1	1	1	1	1.1	1.9	1.8	2.4	3.4	2.5	1.5	0.8	0.9	1.0
1	1	1	2	4.6	4.3	3.1	1.9	2.0	1.6	1.5	2.3	2.0	2.0
1	1	2	1	3.9	7.9	7.3	4.0	2.8	3.1	2.6	2.3	2.0	1.4
1	1	2	2	2.3	3.6	4.0	6.1	2.6	2.9	1.6	1.8	3.0	2.8
1	2	1	1	0.8	0.5	0.5	0.9	0.5	0.6	0.5	0.8	0.5	0.5
1	2	1	2	0.8	0.5	1.3	0.8	0.8	0.5	0.5	0.5	0.5	0.5
1	2	2	1	1.4	5.9	3.0	2.4	3.1	1.5	3.4	1.4	2.9	2.8
1	2	2	2	1.5	0.9	0.6	0.8	1.8	0.5	0.5	1.0	1.3	0.9
2	1	1	1	4.0	2.4	1.8	2.4	1.0	1.1	1.4	0.9	1.3	0.9
2	1	1	2	6.1	7.8	6.1	6.1	4.9	3.3	3.1	3.6	3.0	2.8
2	1	2	1	2.0	7.9	8.0	5.5	6.4	7.3	6.8	3.8	5.1	5.8
2	1	2	2	4.5	9.5	8.5	8.4	5.6	4.3	4.6	4.8	5.5	3.1
2	2	1	1	0.5	0.5	2.3	0.5	0.5	0.5	0.5	0.5	0.6	0.5
2	2	1	2	4.5	5.5	3.5	3.8	3.0	2.5	2.8	1.8	2.3	3.0
2	2	2	1	3.4	4.1	2.8	3.1	2.6	3.4	4.6	2.1	2.4	2.8
2	2	2	2	0.5	1.3	1.3	2.8	0.9	0.8	0.6	1.8	1.0	1.3

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

T - Treatment, 1= Frozen 2= Dried

Le - Leaching, 1= First Leaching 2= Second Leaching

Table E21 Red Clover, High N - Volume (mL)

Treatment				Sample									
Lo	In	T	Le	1	2	3	4	5	6	7	8	9	10
1	1	1	1	81	184	517	465	444	360	453	372	298	133
1	1	1	2	347	519	541	495	423	315	428	399	210	120
1	1	2	1	69	223	265	340	283	355	295	348	572	39
1	1	2	2	106	363	464	357	468	485	371	404	227	63
1	2	1	1	318	660	883	987	823	881	846	1005	137	39
1	2	1	2	489	551	565	560	660	606	580	450	210	225
1	2	2	1	513	802	766	843	851	768	798	786	180	45
1	2	2	2	550	737	728	813	680	643	697	634	256	234
2	1	1	1	50	128	185	304	303	328	358	293	219	318
2	1	1	2	351	551	613	555	415	500	401	473	116	49
2	1	2	1	28	215	339	385	428	380	475	443	241	73
2	1	2	2	158	325	417	407	438	414	425	348	128	48
2	2	1	1	198	723	740	728	807	774	943	760	495	335
2	2	1	2	440	915	690	875	863	855	763	778	482	78
2	2	2	1	238	665	703	603	800	678	748	730	313	83
2	2	2	2	475	410	730	815	760	795	790	805	805	470

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

T - Treatment, 1= Frozen 2= Dried

Le - Leaching, 1= First Leaching 2= Second Leaching

Table E22 Red Clover, High N - NH_4-N (mg L^{-1})

Treatment				Sample									
Lo	In	T	Le	1	2	3	4	5	6	7	8	9	10
1	1	1	1	0.9	4.1	2.3	1.3	2.1	1.1	0.8	0.8	0.8	1.3
1	1	1	2	3.5	2.8	2.0	2.4	1.5	1.5	1.4	1.0	0.9	1.4
1	1	2	1	2.2	3.5	3.8	3.4	3.5	4.3	2.4	2.4	1.6	2.8
1	1	2	2	2.8	3.3	2.1	2.0	2.1	1.7	1.3	1.0	0.8	1.2
1	2	1	1	2.0	2.4	1.5	1.4	1.2	1.0	1.1	1.4	1.0	1.3
1	2	1	2	1.6	2.1	2.3	1.5	1.1	1.1	1.1	0.9	0.9	1.0
1	2	2	1	2.9	3.7	2.7	1.8	2.6	2.3	1.7	1.4	1.0	1.2
1	2	2	2	1.8	2.4	1.2	1.0	0.8	0.6	0.6	0.5	0.5	0.7
2	1	1	1	2.1	5.2	6.0	5.0	4.7	5.0	4.7	2.9	2.9	3.7
2	1	1	2	5.4	5.1	4.0	3.4	2.8	2.7	2.3	1.8	3.4	3.6
2	1	2	1	2.8	6.9	9.4	5.8	4.8	7.2	4.0	4.1	4.9	5.3
2	1	2	2	3.8	4.5	3.7	3.9	2.3	4.5	2.1	2.1	2.9	2.7
2	2	1	1	1.8	3.0	2.9	2.5	2.1	3.5	1.3	1.2	1.4	1.9
2	2	1	2	3.0	4.0	4.4	2.3	1.9	1.3	1.0	1.1	1.7	1.7
2	2	2	1	4.8	5.2	5.0	6.5	3.7	3.3	3.4	2.6	4.0	4.9
2	2	2	2	1.1	1.7	1.5	1.2	1.7	0.9	0.8	1.4	1.0	1.0

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

T - Treatment, 1= Frozen 2= Dried

Le - Leaching, 1= First Leaching 2= Second Leaching

Table E23 Red Clover, High N - NO_3-N (mg L^{-1})

Treatment				Sample									
Lo	In	T	Le	1	2	3	4	5	6	7	8	9	10
1	1	1	1	3.3	8.2	5.7	3.8	5.5	3.0	3.0	4.0	3.5	3.5
1	1	1	2	4.6	3.9	3.5	7.8	4.6	5.3	6.0	3.7	3.6	4.5
1	1	2	1	4.8	5.9	6.7	6.0	6.4	9.5	6.5	6.8	5.3	6.0
1	1	2	2	4.0	7.1	3.8	4.5	6.2	5.0	4.5	3.5	4.1	3.6
1	2	1	1	4.1	4.9	3.3	4.0	4.5	3.9	3.2	7.8	4.0	3.2
1	2	1	2	3.7	4.3	7.9	6.3	3.5	4.4	4.4	3.4	3.5	4.0
1	2	2	1	6.7	7.0	5.2	4.3	9.2	9.6	8.8	5.1	3.5	3.1
1	2	2	2	4.3	8.2	3.8	4.9	4.0	4.0	4.2	3.3	3.1	3.9
2	1	1	1	6.6	7.2	7.4	5.3	5.2	8.1	8.9	4.5	5.0	6.2
2	1	1	2	4.7	4.9	4.8	5.1	4.4	5.4	4.7	3.6	9.4	7.7
2	1	2	1	6.2	6.9	11.5	5.2	5.3	11.8	4.8	6.8	9.8	7.6
2	1	2	2	7.6	5.2	5.0	6.0	3.6	10.6	4.7	5.0	6.1	4.3
2	2	1	1	4.6	5.1	4.5	5.2	5.3	10.9	3.9	3.8	5.6	4.8
2	2	1	2	6.0	5.6	7.7	3.9	3.8	4.6	4.0	4.7	7.9	3.9
2	2	2	1	4.4	3.7	4.4	7.8	4.2	3.2	4.4	3.5	7.9	4.0
2	2	2	2	2.7	3.9	4.1	3.6	8.6	3.6	3.6	8.7	6.0	5.0

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

T - Treatment, 1= Frozen 2= Dried

Le - Leaching, 1= First Leaching 2= Second Leaching

Table E24 Red Clover, High N - P (mg L^{-1})

Treatment				Sample									
Lo	In	T	Le	1	2	3	4	5	6	7	8	9	10
1	1	1	1	3.5	3.6	6.0	3.6	2.9	2.0	2.8	2.5	2.0	1.5
1	1	1	2	5.0	4.5	3.3	3.0	1.8	2.3	2.0	1.5	2.0	2.3
1	1	2	1	2.9	7.4	9.0	7.9	8.4	9.0	5.1	6.3	4.0	4.1
1	1	2	2	3.8	9.1	5.8	5.8	5.6	4.8	3.0	2.5	2.0	3.4
1	2	1	1	1.9	2.9	1.9	1.4	2.8	1.4	1.3	1.1	1.6	2.3
1	2	1	2	1.6	3.5	3.4	2.6	1.4	1.9	1.5	1.0	0.8	1.4
1	2	2	1	2.5	5.1	4.4	3.0	4.0	4.6	3.0	3.3	1.6	2.4
1	2	2	2	2.4	4.4	1.3	1.0	0.5	0.3	0.3	0.3	0.5	1.1
2	1	1	1	2.0	4.4	2.5	3.0	3.9	2.9	3.9	2.1	2.6	5.8
2	1	1	2	13.0	12.3	9.6	8.8	6.8	6.9	5.1	4.5	7.0	7.8
2	1	2	1	1.6	7.0	12.4	8.1	6.4	10.9	6.5	6.1	8.3	8.5
2	1	2	2	5.6	4.9	8.1	8.4	5.8	8.3	5.8	5.8	6.1	6.1
2	2	1	1	1.9	4.8	4.6	3.3	3.3	8.0	1.9	2.3	2.4	3.8
2	2	1	2	4.0	8.0	8.0	3.3	2.5	2.3	2.0	2.3	4.3	3.3
2	2	2	1	2.8	4.9	4.4	6.1	3.5	2.9	3.8	2.5	4.3	5.0
2	2	2	2	1.5	2.5	2.5	1.5	3.5	1.0	1.0	3.5	2.0	2.0

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

T - Treatment, 1= Frozen 2= Dried

Le - Leaching, 1= First Leaching 2= Second Leaching

Appendix F

Weighted mean concentration of NH_4-N, NO_3-N, and P in leachates from cover crops and statistical significance of effects

(Mean of two replicates)

Table F1 Weighted mean concentration of NH_4-N

Treatment				Ryegrass		Oilseed Radish		Red Clover	
Le	Lo	T	In	Low N	High N	Low N	High N	Low N	High N
						mg L^{-1}			
1	1	1	1	0.99	1.99	1.66	1.42	1.87	1.51
1	1	1	2	0.81	1.00	0.73	0.87	1.06	1.42
1	1	2	1	2.12	2.44	5.45	2.07	1.61	2.71
1	1	2	2	0.72	1.21	1.55	1.10	1.82	2.31
1	2	1	1	1.39	3.11	2.16	2.44	2.57	3.85
1	2	1	2	0.82	1.50	1.06	1.28	1.66	2.19
1	2	2	1	1.59	2.43	2.35	2.79	3.15	5.69
1	2	2	2	1.02	1.41	1.91	2.55	6.73	4.28
2	1	1	1	0.76	1.58	1.40	1.56	1.33	1.91
2	1	1	2	0.81	0.99	1.13	1.42	0.69	1.35
2	1	2	1	1.06	1.38	4.61	3.30	1.72	1.78
2	1	2	2	0.57	1.53	1.41	1.81	0.68	1.08
2	2	1	1	1.90	3.40	2.15	2.86	2.37	3.40
2	2	1	2	1.02	1.74	1.32	1.66	1.39	2.31
2	2	2	1	1.35	3.30	6.18	4.46	2.63	3.15
2	2	2	2	1.16	0.87	2.28	3.21	0.91	1.23

Le - Leaching, 1= First Leaching 2= Second Leaching

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

T - Treatment, 1= Frozen 2= Dried

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

Table F2

Statistical significance of Weighted Mean Concentration of NH_4-N

	Ryegrass		Oilseed Radish		Red Clover	
Variable	Low N	High N	Low N	High N	Low N	High N
Lo		**		**	*	**
In		**	**	**		*
T			**	**		
Le	*			**		*
Lo x In		**				
Lo x T		*				
Lo x Le						
In x T						
In x Le						
T x Le						*
Lo x In x T						
Lo x In x Le		*				
Lo x T x Le						
In x T x Le						
Lo x In x T x Le						

Level of significance: ** P< 0.01 ; *P< 0.05 ; blank - n.s.

Lo = Loading Rate

In = Rainfall Intensity

T = Treatment (Frozen or Dried)

Le = Leaching (First or Second)

Table F3 Weighted mean concentration of NO_3-N

Treatment				Ryegrass		Oilseed Radish		Red Clover	
Le	Lo	T	In	Low N	High N	Low N	High N	Low N	High N
						mg L^{-1}			
1	1	1	1	5.44	5.07	13.20	11.04	7.26	4.28
1	1	1	2	4.74	6.56	8.12	7.22	4.38	4.55
1	1	2	1	7.40	6.73	9.32	10.10	5.69	6.37
1	1	2	2	6.32	4.01	9.46	9.04	7.83	6.85
1	2	1	1	4.05	7.08	14.33	17.24	6.59	6.09
1	2	1	2	6.89	5.50	10.06	10.26	7.80	5.35
1	2	2	1	6.84	5.37	11.25	15.00	6.93	7.45
1	2	2	2	4.57	5.93	9.42	9.95	4.63	4.77
2	1	1	1	4.71	5.86	8.42	7.51	4.71	4.83
2	1	1	2	4.07	4.78	5.99	7.62	4.82	4.74
2	1	2	1	3.95	4.95	8.80	5.41	6.02	4.81
2	1	2	2	4.08	4.58	4.51	5.34	5.74	4.59
2	2	1	1	7.83	8.38	9.60	10.62	5.32	4.84
2	2	1	2	4.43	4.08	6.55	6.85	5.57	5.16
2	2	2	1	5.05	5.94	9.13	6.14	7.96	5.84
2	2	2	2	4.25	4.12	4.70	6.85	4.17	5.13

Le - Leaching, 1= First Leaching 2= Second Leaching

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

T - Treatment, 1= Frozen 2= Dried

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

Table F4

Statistical significance of Weighted Mean Concentration of NO_3-N

Variable	Annual Rye		Oilseed Radish		Red Clover	
	Low N	High N	Low N	High N	Low N	High N
Lo				*		
In		*	*	*		
T						
Le	*		*	**		
Lo x In						
Lo x T						
Lo x Le						
In x T						
In x Le						
T x Le	*					
Lo x In x T					*	
Lo x In x Le						
Lo x T x Le						
In x T x Le	*					
Lo x In x T x Le						

Level of significance: ** $P < 0.01$; *$P < 0.05$; blank - n.s.

Lo = Loading Rate

In = Rainfall Intensity

T = Treatment (Frozen or Dried)

Le = Leaching (First or Second)

Table F5 Weighted mean concentration of P

Treatment				Ryegrass		Oilseed Radish		Red Clover	
Le	Lo	T	In	Low N	High N	Low N	High N	Low N	High N
						mg L^{-1}			
1	1	1	1	5.47	8.99	9.73	12.30	1.86	3.16
1	1	1	2	2.82	5.72	7.39	1.13	0.60	1.79
1	1	2	1	5.83	9.11	12.81	16.66	4.04	6.21
1	1	2	2	5.67	3.45	11.37	13.16	2.83	3.72
1	2	1	1	7.81	13.54	14.14	15.71	1.37	3.13
1	2	1	2	6.74	8.12	8.62	6.06	0.64	3.74
1	2	2	1	11.42	11.99	18.76	26.79	5.85	7.99
1	2	2	2	3.36	8.57	13.20	21.02	3.20	3.97
2	1	1	1	4.92	5.60	9.06	11.32	2.49	2.82
2	1	1	2	2.35	3.30	4.70	8.41	0.66	1.88
2	1	2	1	5.77	5.14	14.30	11.92	3.07	4.64
2	1	2	2	1.46	3.59	3.01	5.23	1.01	1.26
2	2	1	1	13.69	17.47	18.69	20.89	4.87	8.14
2	2	1	2	6.78	6.06	6.02	11.65	3.29	4.09
2	2	2	1	8.18	16.23	20.14	13.91	6.40	6.55
2	2	2	2	4.59	2.44	5.89	7.72	1.24	2.10

Le - Leaching, 1= First Leaching 2= Second Leaching

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

T - Treatment, 1= Frozen 2= Dried

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

Table F6

Statistical significance of Weighted Mean Concentration of P

	Annual Rye		Oilseed Radish		Red Clover	
Variable	Low N	High N	Low N	High N	Low N	High N
Lo	**	**	**	*	*	
In	**	**	**	**	**	*
T					*	
Le						
Lo x In		*				
Lo x T						
Lo x Le						
In x T						
In x Le			*			
T x Le				**	*	
Lo x In x T						
Lo x In x Le		*				
Lo x T x Le						
In x T x Le						
Lo x In x T x Le	*					

Level of significance: ** $P < 0.01$; *$P < 0.05$; blank - n.s.

Lo = Loading Rate

In = Rainfall Intensity

T = Treatment (Frozen or Dried)

Le = Leaching (First or Second)

Appendix G

Amount of nutrient leached per unit weight of cover crop (mg kg^{-1}) and statistical significance of effects.

(Mean of two replicates)

Table G1 Amount of NH_4-N leached per unit weight of cover crop

Treatment				Ryegrass		Oilseed Radish		Red Clover	
Le	Lo	T	In	Low N	High N	Low N	High N	Low N	High N
						mg kg^{-1}			
1	1	1	1	43	86	105	86	97	101
1	1	1	2	101	137	94	121	147	187
1	1	2	1	133	152	217	119	113	147
1	1	2	2	93	159	193	135	201	293
1	2	1	1	21	88	72	80	87	133
1	2	1	2	55	98	64	80	103	141
1	2	2	1	41	65	75	80	101	174
1	2	2	2	63	87	129	158	386	247
2	1	1	1	58	129	138	136	82	154
2	1	1	2	106	127	151	175	89	120
2	1	2	1	64	93	255	182	99	125
2	1	2	2	81	194	163	192	90	128
2	2	1	1	73	130	89	100	71	138
2	2	1	2	68	129	88	104	88	155
2	2	2	1	42	88	166	127	76	105
2	2	2	2	73	53	149	196	55	84

Le - Leaching, 1= First Leaching 2= Second Leaching

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

T - Treatment, 1= Frozen 2= Dried

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

Table G2 Statistical significance of effects - NH_4-N

	Annual Rye		Oilseed Radish		Red Clover	
Variable	Low N	High N	Low N	High N	Low N	High N
Lo		**	*	**		
In				**		
T			**	**		
Le				**		
Lo x In						
Lo x T		*				
Lo x Le						
In x T						
In x Le						
T x Le						
Lo x In x T				*		
Lo x In x Le						
Lo x T x Le						
In x T x Le						
Lo x In x T x Le						

Level of significance: ** $P< 0.01$; *$P< 0.05$; blank - n.s.

Lo = Loading Rate

In = Rainfall Intensity

T = Treatment (Frozen or Dried)

Le = Leaching (First or Second)

Table G3 Amount of NO_3-N leached per unit weight of cover crop

Treatment				Ryegrass		Oilseed Radish		Red Clover	
Le	Lo	T	In	Low N	High N	Low N	High N	Low N	High N
						mg kg^{-1}			
1	1	1	1	252	242	806	634	389	274
1	1	1	2	556	898	1009	1007	608	603
1	1	2	1	438	412	438	563	406	349
1	1	2	2	805	522	1190	1115	913	870
1	2	1	1	70	199	482	560	223	206
1	2	1	2	460	359	624	647	495	349
1	2	2	1	183	147	385	430	219	213
1	2	2	2	283	386	620	623	241	255
2	1	1	1	355	487	693	609	290	383
2	1	1	2	539	608	798	916	635	492
2	1	2	1	280	333	491	297	346	334
2	1	2	2	596	571	515	569	762	538
2	2	1	1	300	320	389	365	162	197
2	2	1	2	295	299	437	428	351	348
2	2	2	1	167	163	244	174	228	188
2	2	2	2	263	256	306	416	255	352

Le - Leaching, 1= First Leaching 2= Second Leaching

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

T - Treatment, 1= Frozen 2= Dried

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

Table G4 Statistical significnce of effects - NO_3-N

	Annual Rye		Oilseed Radish		Red Clover	
Variable	Low N	High N	Low N	High N	Low N	High N
Lo	**	**	**	**	**	**
In	**	**		**	**	**
T				*		
Le			*	**		
Lo x In					*	
Lo x T					*	
Lo x Le						
In x T						
In x Le		*				
T x Le						
Lo x In x T						
Lo x In x Le						
Lo x T x Le						
In x T x Le						
Lo x In x T x Le						

Level of significance: ** $P< 0.01$; *$P< 0.05$; blank - n.s.

Lo = Loading Rate

In = Rainfall Intensity

T = Treatment (Frozen or Dried)

Le = Leaching (First or Second)

Table G5 Amount of P leached per unit weight of cover crop

Treatment				Ryegrass		Oilseed Radish		Red Clover	
Le	Lo	T	In	Low N	High N	Low N	High N	Low N	High N
						mg kg^{-1}			
1	1	1	1	249	412	615	736	108	185
1	1	1	2	338	778	918	161	83	232
1	1	2	1	347	558	609	933	290	330
1	1	2	2	724	463	1425	1622	340	472
1	2	1	1	127	383	472	527	46	83
1	2	1	2	449	532	536	390	39	241
1	2	2	1	303	324	648	771	183	228
1	2	2	2	206	544	857	1303	154	203
2	1	1	1	369	468	802	928	153	172
2	1	1	2	312	424	628	1044	87	167
2	1	2	1	351	346	764	615	169	323
2	1	2	2	224	481	345	550	134	148
2	2	1	1	513	649	712	704	138	327
2	2	1	2	452	441	401	728	209	275
2	2	2	1	258	418	523	387	186	201
2	2	2	2	289	151	387	471	76	144

Le - Leaching, 1= First Leaching 2= Second Leaching

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

T - Treatment, 1= Frozen 2= Dried

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

Table G6 Statistical significance of effects - P

Variable	Annual Rye		Oilseed Radish		Red Clover	
	Low N	High N	Low N	High N	Low N	High N
Lo			*			
In						
T					**	
Le			*			
Lo x In						
Lo x T	*					
Lo x Le	*				*	
In x T				*		
In x Le	**	*	**			
T x Le	**		*	**	**	
Lo x In x T						
Lo x In x Le						
Lo x T x Le						
In x T x Le				*		
Lo x In x T x Le	*					

Level of significance: ** P< 0.01 ; *P< 0.05 ; blank - n.s.

Lo = Loading Rate

In = Rainfall Intensity

T = Treatment (Frozen or Dried)

Le = Leaching (First or Second)

Appendix H

Proportion of N and P removed from cover crop biomass by leaching.

(Mean of two replicates)

Table H1 Proportion of N content of biomass removed by leaching

Treatment				Ryegrass		Oilseed Radish		Red Clover	
Le	Lo	T	In	Low N	High N	Low N	High N	Low N	High N
							%		
1	1	1	1	3.03	2.08	6.34	5.58	3.68	1.80
1	1	1	2	9.14	6.57	7.67	8.75	5.71	3.78
1	1	2	1	5.85	3.59	4.56	5.29	3.93	2.37
1	1	2	2	9.20	4.33	9.62	9.69	8.44	5.56
1	2	1	1	0.93	1.82	3.86	4.96	2.35	1.63
1	2	1	2	5.28	2.91	4.79	5.64	4.54	2.35
1	2	2	1	2.30	1.35	3.20	3.96	2.45	1.85
1	2	2	2	3.55	3.01	5.21	6.05	4.75	2.40
2	1	1	1	4.23	3.92	5.78	5.78	2.81	2.57
2	1	1	2	6.61	4.67	6.60	8.46	5.48	2.93
2	1	2	1	3.52	2.71	5.19	3.71	3.36	2.20
2	1	2	2	6.94	4.86	4.72	5.90	6.45	3.18
2	2	1	1	3.83	2.86	3.32	3.61	1.77	1.60
2	2	1	2	3.73	2.72	3.65	4.12	3.32	2.41
2	2	2	1	2.15	1.60	2.86	2.33	2.31	1.40
2	2	2	2	3.44	1.97	3.17	4.74	2.35	2.08

Le - Leaching, 1= First Leaching 2= Second Leaching

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

T - Treatment, 1= Frozen 2= Dried

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}

Table H2 Proportion of P content of biomass removed by leaching

Treatment				Ryegrass		Oilseed Radish		Red Clover	
Le	Lo	T	In	Low N	High N	Low N	High N	Low N	High N
							%		
1	1	1	1	10.92	12.95	14.43	16.66	7.01	7.57
1	1	1	2	24.41	24.48	21.54	3.65	5.39	9.52
1	1	2	1	15.24	17.57	14.29	21.12	18.84	13.52
1	1	2	2	31.47	14.56	33.47	36.70	22.08	19.36
1	2	1	1	5.62	12.09	11.10	11.92	3.02	3.40
1	2	1	2	19.82	16.77	12.62	8.83	2.56	9.87
1	2	2	1	13.33	10.21	15.25	17.44	11.96	9.35
1	2	2	2	9.07	17.16	20.16	29.48	10.08	8.31
2	1	1	1	16.20	14.73	18.82	21.00	9.93	7.04
2	1	1	2	13.70	13.32	14.74	23.61	5.64	6.87
2	1	2	1	15.41	10.87	17.94	13.92	10.98	13.24
2	1	2	2	9.83	15.14	8.10	12.44	8.71	6.08
2	2	1	1	22.59	20.47	16.74	15.92	9.02	13.42
2	2	1	2	19.93	13.92	9.44	16.46	13.64	11.26
2	2	2	1	11.37	13.18	12.31	8.76	12.16	8.23
2	2	2	2	12.72	4.75	9.10	10.65	4.99	5.90

Le - Leaching, 1= First Leaching 2= Second Leaching

Lo - Loading Rate, 1= 2000 kg ha^{-1} 2= 4000 kg ha^{-1}

T - Treatment, 1= Frozen 2= Dried

In - Rainfall Intensity, 1= 2 cm hr^{-1} 2= 4 cm hr^{-1}